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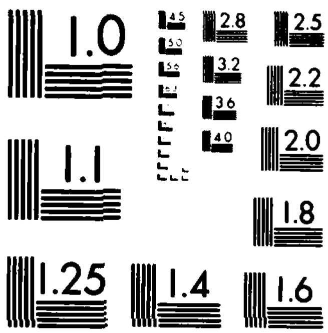

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US Army Corps of Engineers

COMPUTER-AIDED STRUCTURAL ENGINEERING (CASE) PROJECT

INSTRUCTION REPORT K-84-8

SEEPAGE ANALYSIS OF CONFINED FLOW PROBLEMS BY THE METHOD OF FRAGMENTS (CFRAG)

DTIC FILE COPY

by

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Confined flow
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Seepage analysis
Uplift pressures

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents CFRAG, a computer program for the seepage analysis of confined groundwater flow by the method of fragments. The program provides the following information:

a. The flow per unit width through the specified soil medium.
b. The head loss per fragment.
c. The exit gradient.

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20. ABSTRACT (Continued)

d. The resultant uplift and lateral forces acting on the structure.

e. A sketch of the structure with uplift and lateral pressure diagrams drawn appropriately.

Data can be input by an interactive question-and-answer session, by a previously created data file, or by a pictorial menu using the crosshairs to select fragment types.

The report presents example computer results with hand verification and example problems with comparisons made among the method of fragments, flownets, method of creep, and finite element analysis. It also presents a parametric study of a simple hydraulic structure to illustrate the effect on the solutions obtained by the various methods when the geometry of the structure is altered.

PREFACE

This user's guide documents CFRAG, a computer program for the seepage analysis of confined groundwater flow of finite depth.

Funding for the development of the program and preparation of the user's guide was provided to the Automatic Data Processing (ADP) Center, U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., by the Civil Works Directorate of the Office, Chief of Engineers (OCE), U. S. Army, under the Geotechnical Aspects of the Computer-Aided Structural Engineering (CASE) Project.

Specifications for the program were prepared by the members of the CASE Task Group on Geotechnical Aspects of CASE. Members of the task group during the development of the program were as follows:

Dr. Roger Brown, South Atlantic Division
Mr. Larry Cooley, Vicksburg District
Mr. Frank Coopinger, North Atlantic Division
Mr. Richard Davidson, OCE
Mr. Ed Demsky, St. Louis District
Mr. Lavane Dempsey, St. Paul District
Mr. Phil Napolitano, New Orleans District (Chairman)
Mr. Bill Strohm, Waterways Experiment Station
Mr. Charles Trahan, Lower Miss. Valley Division
Mr. Tom Wolff, St. Louis District

The program was written by Mr. Michael E. Pace with technical assistance from Mr. Reed L. Mosher, Computer-Aided Design (CAD) Group, ADP Center, WES.

The report was written by Michael E. Pace under the guidance of Mr. Mosher and Mr. Dennis R. Williams, CAD Group, ADP Center, WES. Additions and comments were supplied by Mr. Williams, Mr. Mosher, and Mr. Thomas Wolff, St. Louis District. All hand computations and comparisons were performed by Mr. Pace. The work was managed and coordinated by Dr. N. Radhakrishnan, Chief, ADP Center, WES, and CASE Project Manager. Messrs. Richard Davidson and Donald M. Dressler were the OCE points of contact.

Commander and Director of WES during the development of the program and publication of this report was COL Tilford C. Creel, CE. Technical Director was Mr. Frederick R. Brown.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet per day	0.02831	cubic meters per day
feet	0.3048	meters
kips (1000 lb force)	4.448222	kilonewtons
kips (force) per square foot	47.880263	kilopascals
pound-force	4.448	newtons
pounds (force) per square foot	47.880263	pascals
pounds (mass) per cubic foot	16.018463	kilograms per cubic meter

SEEPAGE ANALYSIS OF CONFINED FLOW PROBLEMS BY THE METHOD OF FRAGMENTS (CFRAG)

PART I: INTRODUCTION

Purpose of Program CFRAG*

1. This report describes CFRAG, a computer program designed for the analysis of confined groundwater flow. Flow computations are performed using the method of fragments, first introduced by N. N. Pavlovsky in 1935** and later presented by M. E. Harr.[†,††] The program will provide the following information:

   a. The flow per unit width through the specified soil medium.

   b. The head loss per fragment.

   c. The exit gradient for certain fragment types.

   d. The resultant uplift and lateral forces acting on the structure.

   e. A sketch of the structure with uplift and lateral pressure diagrams drawn appropriately.

Organization of Report

2. The remainder of this report is organized as follows:

   a. Part II presents an overview of the method of fragments and the analysis procedure employed in the program.

   b. Part III describes the user's guide for data input and for execution of the program.

   c. Appendix A presents example computer runs and hand verifications.

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* Three sheets entitled "Program Information" have been hand-inserted inside the front cover of this report. They present general information on the program and describe how it can be accessed. If procedures used to access this and other CORPS library programs should change, recipients of this report will be furnished a revised version of the "Program Information."

** N. N. Pavlovsky. 1956. Collected Works, Akad. Nauk, USSR, Leningrad.

† M. E. Harr. 1962. Groundwater and Seepage, McGraw-Hill Book Company, New York, pp 159-165.

†† __________. 1977. Mechanics of Particulate Media, McGraw-Hill Book Company, New York, pp 171-174.

d. Appendix B gives additional example problems and presents a comparison of solutions using the method of fragments, flownets, and a finite element method computer program. The method of creep is also used in the comparison of uplift pressures.

e. Appendix C presents a simple hydraulic structure and illustrates the effect on solutions obtained by the various methods when the geometry of the structure is altered.

PART II: ANALYSIS PROCEDURE

Basic Assumptions

3. The method of fragments is an approximate analytical procedure for computing groundwater flow. ~~The~~ principal assumptions used in the derivation of this method are as follows:

- a. The flow is confined and of finite depth.
- b. Darcy's law is valid; therefore, laminar flow exists.
- c. A steady state flow exists.
- d. The soil medium is homogeneous and isotropic.
- e. Equipotential lines at certain locations of the flow region can be approximated by vertical lines (Figure 1).

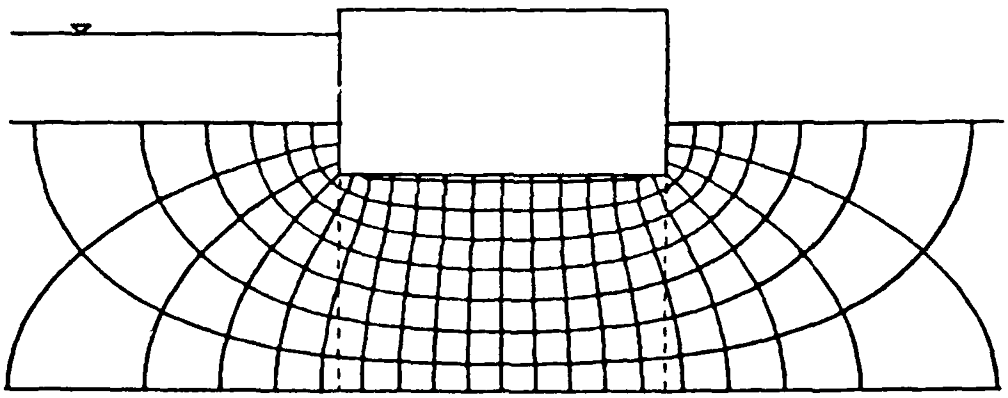

Figure 1. Approximation of actual equipotential lines by vertical lines

Development of Equations of Flow and Head Loss for the Method of Fragments

4. The method of fragments describes the flow through a porous medium by the expression

$$q = k \frac{h}{\Phi} \qquad (1)$$

where

q = quantity of flow

k = coefficient of permeability

h = total head loss

Φ = dimensionless form factor

5. In the analysis of seepage by flownets, the form factor Φ corresponds to the ratio N_e/N_f (Figure 2), and the total flow is expressed by

$$q = k \frac{h}{N_e/N_f} = kh \frac{N_f}{N_e} \tag{2}$$

in which

N_e = the total number of equipotential drops occurring within the flow region

and

N_f = the total number of flow channels corresponding to N_e .

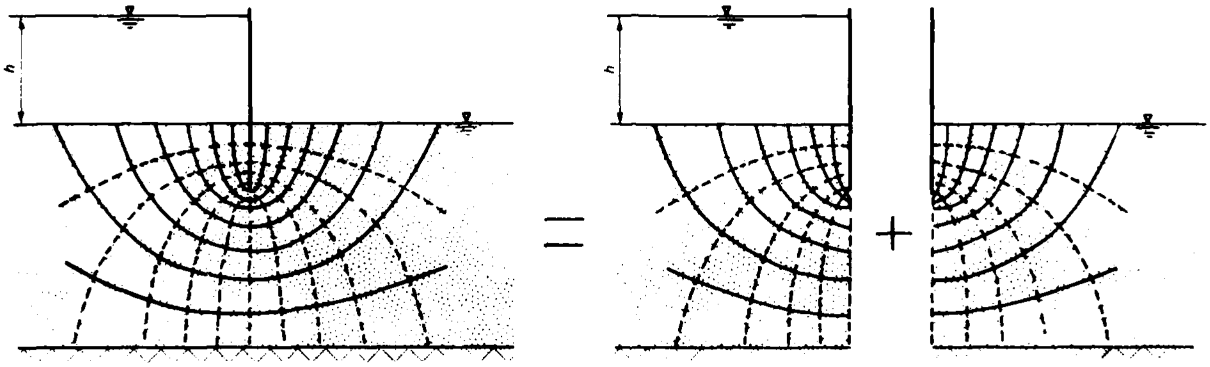

Figure 2. Simple flownet divided into fragments

6. Groundwater flow is analyzed using the method of fragments by assuming that a flow regime can be represented as an assemblage of smaller flow regimes, or fragments, for which form factors are known.

7. From Figure 2 we observe that the flow across any equipotential line is constant and is equal to the total quantity of flow for the system. If the flow region in Figure 2 is divided along the equipotential line extending from the tip of the sheetpile, the flow region is separated into two fragments. Since the fragment boundaries consist of equipotential lines, the flow through each fragment must be identical and equal to the total quantity of flow through the system.

$$q = q_1 = q_2$$

Extending this concept to a more general flow system divided into n fragments, we observe that

$$q = q_1 = q_2 \cdots = q_i \cdots = q_n \tag{3}$$

8. In Figure 2, N_e/N_f represents a form factor for the entire flow region. Similarly for each fragment, the sum of the equipotential drops divided by the number of flow channels in the fragment is the form factor for that fragment. Therefore, the head loss in any fragment may be expressed as

$$h_i = \frac{q}{k} \Phi_i \tag{4}$$

where

h_i = head loss in ith fragment

Φ_i = form factor for ith fragment

9. The head losses for the fragments shown in Figure 2 are,

$$h_1 = \frac{q}{k} \Phi_1$$

and

$$h_2 = \frac{q}{k} \Phi_2$$

Solving for q and combining with equation (3)

$$q = \frac{kh_1}{\Phi_1} = \frac{kh_2}{\Phi_2}$$

For a more general case containing n fragments

$$q = \frac{kh_1}{\Phi_1} = \frac{kh_2}{\Phi_2} \cdots = \frac{kh_i}{\Phi_i} \cdots = \frac{kh_n}{\Phi_n} \tag{5}$$

10. For the total flow region the quantity of flow may be expressed as

$$q = k \frac{\sum_{i=1}^{n} h_i}{\sum_{i=1}^{n} \Phi_i} = \frac{kh}{\Phi_T} \qquad (6)$$

where

h = total head loss

Φ_T = sum of the individual form factors for the flow region

11. If equations (5) and (6) are combined, the head loss for the ith fragment is

$$h_i = h \frac{\Phi_i}{\Phi_T} \qquad (7)$$

This relationship may also be related to flownets as

$$h_i = h \frac{N_{e_i}}{N_e} \qquad (8)$$

where

N_{e_i} = equipotential drops within fragment i .

12. If a flow region can be divided into fragments, for which the form factors are known, then the head loss for each fragment can be determined. Once the head loss for each fragment has been determined, the pressure distribution and quantity of flow can also be obtained.

Fragment Types

13. The method of fragments is a method of solving the general flow equation by dividing the flow region into fragments for which form factors are known. Unfortunately, except for the simplest of fragments, form factors are extremely difficult to determine. However, Pavlosky* was able to develop mathematical solutions for a number of fragment types by assuming that the

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* Op. cit., p 4.

equipotential lines on fragment boundaries could be approximated by vertical lines.

14. In the following paragraphs a brief derivation of six form factors is presented. The content of this section is based on the method of fragments as presented by Harr*.

Fragment type 1

15. Fragment type 1 (Figure 3a) is a region describing parallel flow between two horizontal impervious boundaries. From Darcy's law for a flow system of unit area a,

$$q = kia = k \frac{h}{L} a \tag{9a}$$

which when rearranged

$$q = kh \frac{a}{L} = kh \frac{1}{L/a} \tag{9b}$$

From the general flow equation we see that the form factor is

$$\Phi = \frac{L}{a} \tag{10}$$

16. For an elemental section (Figure 3b)

$$d\Phi = \frac{dx}{y} \tag{11}$$

This elemental section will be used to derive the form factors for fragments 4, 5, and 6.

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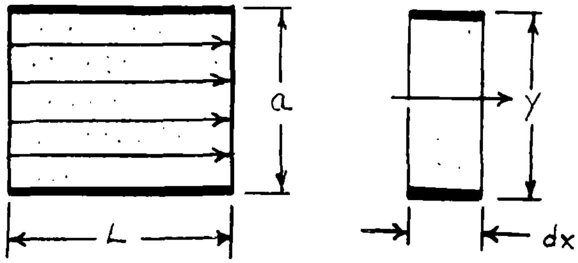
* Op. cit., p 4.



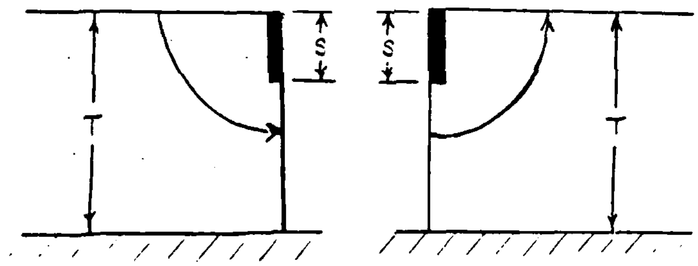
a. Flow between horizontal impervious boundaries

b. Elemental section of flow

Figure 3. Fragment type 1

Fragment type 2

17. Fragment type 2 (Figure 4) is a vertical impervious boundary embedded a distance s into a pervious layer of thickness T . This fragment is either an entrance (Figure 4a) or an exit (Figure 4b) fragment.



a. Entrance

b. Exit

Figure 4. Fragment type 2

18. The quantity of flow for this fragment is given by

$$q = kh \frac{K'}{K} \tag{12}$$

where

K = complete elliptic integral of the first kind of modulus m*

K' = complete elliptic integral of the first kind of complementary modulus m'

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* See Harr (1962), Appendix B, for a table of elliptic integrals of the first kind.

and

$$m = \sin \frac{\pi s}{2T} \tag{13}$$

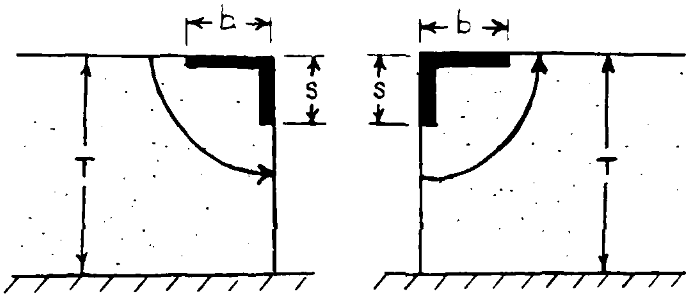
$$m'^2 = 1 - m^2 \tag{14}$$

The form factor can be expressed as

$$\Phi = \frac{K}{K'} \tag{15}$$

Fragment type 3

19. Fragment type 3 (Figure 5) is an impervious boundary of length b and embedment s in a pervious layer of thickness T . Like fragment type 2, it is also an entrance (Figure 5a) or exit (Figure 5b) fragment.



a. Entrance b. Exit

Figure 5. Fragment type 3

20. The equation for the form factor is the same as for fragment type 2. Therefore, the form factor may also be expressed as

$$\Phi = \frac{K}{K'} \tag{16}$$

The elliptic integrals K and K' are computed using the modulus

$$m = \cos \frac{\pi s}{2T} \sqrt{\tanh^2 \frac{\pi b}{2T} + \tan^2 \frac{\pi s}{2T}} \tag{17}$$

Fragment type 4

21. Fragment type 4 (Figure 6) is an impervious boundary of length b and embedment s in a pervious layer of thickness T . A type 4 fragment is

normally considered an internal fragment. On very rare occasions, it may be used as an entrance or exit fragment. However, in CFRAG the type 4 fragment is an internal fragment only.

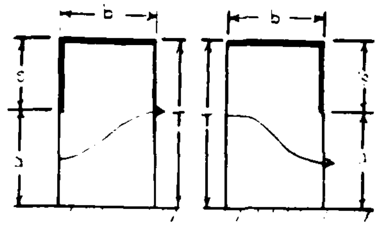


Figure 6. Fragment type 4

22. For the exact solution of a type 4 fragment, the form factor is

$$\Phi = \frac{K'}{K} \tag{18}$$

where K and K' are elliptic integrals as previously defined, but with a modulus given by

$$m = \lambda \mathrm{sn}\left(\frac{a}{T}\,\Lambda,\ \lambda\right) \tag{19}$$

In this equation

Λ = complete elliptic integral of the first kind of modulus λ

Λ' = complete elliptic integral of the first kind of complementary modulus λ'

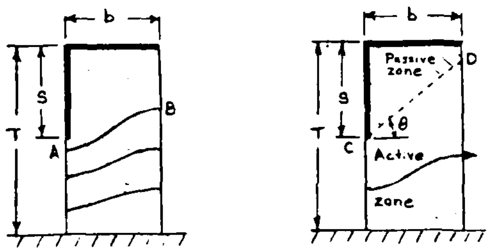
also

$$\frac{\Lambda}{\Lambda'} = \frac{T}{b}$$

The term $\mathrm{sn}\left(\frac{a}{T}\,\Lambda,\ \lambda\right)$ is defined as an elliptic function of $\left(\frac{a}{T}\,\Lambda,\ \lambda\right)$.

23. To simplify the calculations for this fragment, an approximate solution proposed by Pavlovsky is used in CFRAG. From Figure 7a the quantity of seepage above streamline AB was observed by Pavlovsky to be of small order compared to the total flow. Neglecting this flow, Pavlovsky

divided the flow region into two parts labeled active and passive (Figure 7b). The dividing line for the two parts is line CD at an angle θ .



(a) (b)

Figure 7. Flow system for approximate solution of a type 4 fragment

24. On the basis of his studies, Pavlovsky chose $\theta = 45°$. Depending on the ratio of b to s , two form factors are possible.

25. For the case of $b \leq s$ (Figure 8a) the active zone is composed of elements of a type 1 fragment of width dx (Equation 11). Therefore,

$$\Phi = \int_o^b \frac{dx}{y} = \int_o^b \frac{dx}{a + x}$$

Integrating, the form factor is

$$\Phi = \ln\left(1 + \frac{b}{a}\right) \tag{20}$$

For the case of $b \geq s$ (Figure 8b)

$$\Phi = \int_o^s \frac{dx}{a + x} + \int_s^b \frac{dx}{T}$$

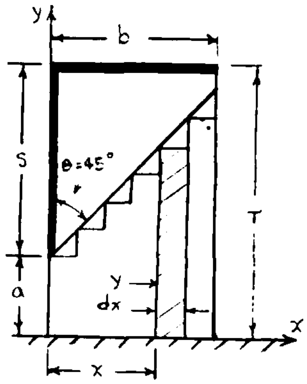
and by integration

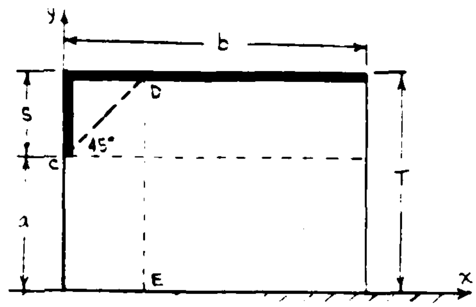
$$\Phi = \ln\left(1 + \frac{s}{a}\right) + \frac{b - s}{T} \tag{21}$$

Notice that in the case of $b > s$ the first term of the equation defines a type 4 fragment of $b \leq s$, while the second term defines a type 1 fragment.

The two fragments are joined at line DE.

a. $b \leq s$





b. $b \geq s$

Figure 8. Fragment type 4

Fragment type 5

26. Fragment type 5 (Figure 9) contains two equal impervious boundaries of embedment s in a pervious layer of thickness T and is separated by a horizontal impervious length L. Observe that fragment type 5 is symmetric and is twice that of fragment type 4. Using the same approximations as for the type 4 fragment, two cases are possible: $L \leq 2s$ and $L \geq 2s$.

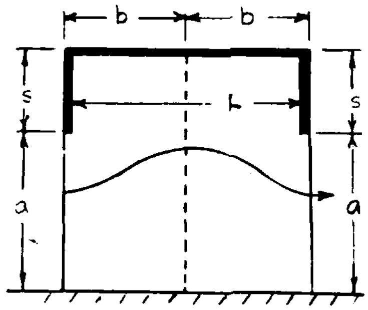


Figure 9. Fragment type 5

For

$L \leq 2s$

$$\Phi = 2 \ln \left(1 + \frac{L}{2a}\right) \tag{22}$$

and for

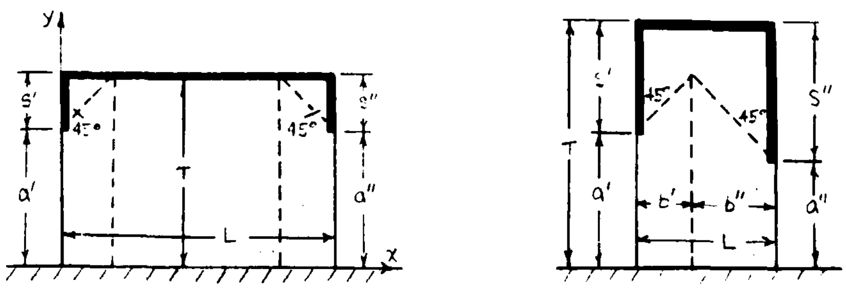
$L \geq 2s$

$$\Phi = 2 \ln \left(1 + \frac{s}{a}\right) + \frac{L - 2s}{T} \tag{23}$$

For the case of $L \geq 2s$, the second term of the equation provides a type 1 fragment that is located between two type 4 fragments.

<u>Fragment type 6</u>

27. Fragment type 6 (Figure 10) is the same as fragment type 5 except that the embedment lengths are unequal. Again, two cases are possible $L \geq (s' + s'')$ and $L \leq (s' + s'')$.



a. $L \geq (s' + s'')$ b. $L \leq (s' + s'')$

Figure 10. Fragment type 6

If the approximations used in fragment type 4 are applied, the form factor for $L \geq (s' + s'')$ (Figure 10a) is

$$\Phi = \int_0^{s'} \frac{dx}{a' + x} + \int_{s'}^{L-s''} \frac{dx}{T} + \int_{L-s''}^{L} \frac{dx}{a'' + L - x}$$

Integrating each term

$$\Phi = \ln\left[\left(1 + \frac{s'}{a'}\right)\left(1 + \frac{s''}{a''}\right)\right] + \frac{L - (s' + s'')}{T} \qquad (24)$$

Similarly for $L \leq (s' + s'')$ (Figure 10b)

$$\Phi = \int_{o}^{b_1} \frac{dx}{a' + x} + \int_{b_1}^{L} \frac{dx}{a'' + L - x}$$

and by integration

$$\Phi = \ln\left[\left(1 + \frac{b'}{a'}\right)\left(1 + \frac{b''}{a''}\right)\right] \qquad (25)$$

where

$$b' = \frac{L + (s' - s'')}{2} \qquad (26)$$

$$b'' = \frac{L - (s' - s'')}{2} \qquad (27)$$

Pressure Calculations

28. The head loss for each fragment can be determined from factors previously developed. From Bernoulli's equation, the pressure head at the entrance and exit boundaries of each fragment is obtained; and by assuming a linear distribution of the head loss within each fragment, the pressure head may also be calculated for points along the interior of the fragment.

29. Recall from Bernoulli's equation for laminar flow that the total head is defined as

$$h = z + \frac{P}{\gamma} \qquad (28)$$

where

z = elevation head

P = pressure

γ = unit weight of water

and that between any two points

$$z_1 + \frac{P_1}{\gamma} = z_2 + \frac{P_2}{\gamma} + \Sigma h_L \qquad (29)$$

where

Σh_L = the sum of head losses between 1 and 2

30. Based on equations (28) and (29), the pressure may be calculated at any point along the fragment boundaries.

31. In CFRAG an arbitrary datum is chosen as the top of the headwater. If this datum is used, Bernoulli's equation reduces to

$$z_2 + \frac{P_2}{\gamma} + \Sigma h_L = 0 \qquad (30a)$$

and

$$P_2 = (-z_2 - \Sigma h_L)\gamma \qquad (30b)$$

32. In Figure 11, the head loss gradient R is approximated by a linear distribution along the boundary $ECC'E'$. Thus,

$$R = \frac{h_m}{L + s' + s''} \qquad (31)$$

where

h_m = head loss for the fragment

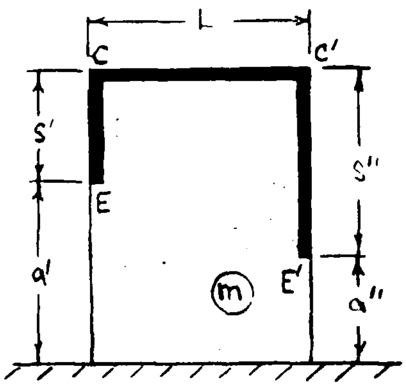


Figure 11. Head loss within a typical fragment

Exit Gradient

33. The exit gradient may be calculated if the last fragment on the downstream side of the defined system is a type 2 fragment. The exit gradient as computed by CFRAG was derived assuming an infinite depth of permeable soil. The exit gradient derived in this manner will yield a conservative answer.

34. The exit gradient is defined as

$$I_E = \frac{h\pi}{2KTm} \tag{32}$$

where

h = head loss through fragment

K = elliptic integral of the first kind

T = depth of flow region

m = modulus

and the modulus is

$$m = \cos\frac{\pi S}{2T}\sqrt{\tanh^2\frac{\pi b}{2T} + \tan^2\frac{\pi S}{2T}} \tag{33}$$

35. Structural configurations which do not have a type 2 fragment on their downstream side would generally be avoided. Without a type 2 fragment as an exit fragment, there is no embedment and subsequently a lack of confinement at the edge of the upper impervious boundary. Gradients and seepage velocities theoretically approach infinity at this point of discontinuity. High local gradients and lack of embedment could initiate piping or "roofing" at this point.

Applicability of the Method of Fragments

36. The method of fragments is well suited for seepage analysis where the physical assumptions of the method (paragraph 3) are satisfied and the following situations apply:

a. The geometry of flow regime is simple, i.e., composed of horizontal and vertical boundaries.

b. The true equipotential lines do not deviate significantly from the fragment boundaries.

c. A reasonably accurate solution is desired in a short time and/or at a low cost.

37. This last situation includes the following class of problems:

a. Sizing of structural features, such as base width, location and depth of a sheetpile, and any other structural features that may require trial solutions.

b. Obtaining pressures on structures, such as floodwalls and weirs, where the results will be used for the analysis of loads on structures in conjunction with experience-based factors of safety.

c. Determining flow quantities.

As was stated in paragraph 3, the soil medium is assumed to be homogeneous and isotropic. However, a homogeneous, anisotropic system may be transformed into an equivalent homogeneous, isotropic system by applying the transformation of $X = x\sqrt{K_y/K_x}$ in the x direction or $Y = y\sqrt{K_x/K_y}$ in the y direction. The equivalent coefficient of permeability for a homogeneous, anistropic section is $K = \sqrt{K_x K_y}$. Some nonhomogeneous systems may be solved by applying a method described by M. E. Harr.*

38. A practical application of the method of fragments is in the estimation of uplift pressures for the design of T-walls. The method is particularly useful in the process of sizing the key and base components and developing a functional relationship between the uplift pressure and the base width or key depth.

39. An example of how a T-wall might be modeled is shown in Figure 12. Since there is essentially no flow in the backfill, the flow is neglected in this area. The key width is also neglected to avoid unnecessarily constraining the flow. The base width accounts for the zero key width because it is equal to the total width of the T-wall.

40. The method of fragments may also be used to calculate exit gradients by dividing the head loss in the exit fragment by the depth of its embedment. The exit gradient may also be calculated by dividing the head loss in an infinitesimal element on the downstream face by its length. The latter method is used in the program.

---

* Op. cit., p 4.

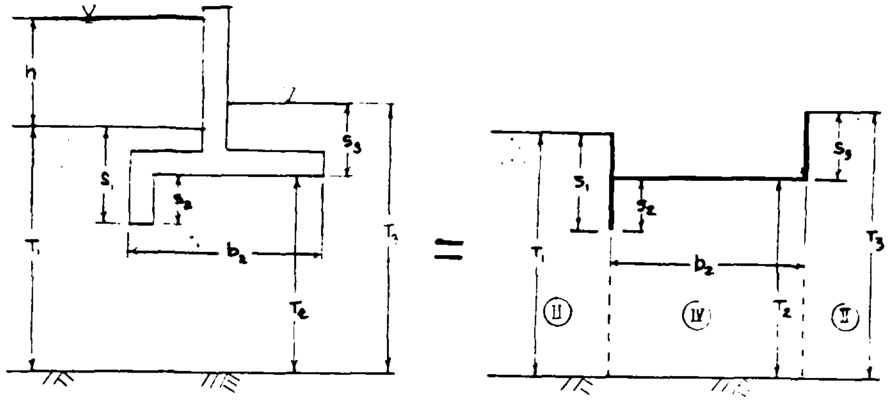


Figure 12. Analysis of T-wall by the method of fragments

Accuracy of the Method of Fragments

41. The method of fragments will yield reasonable results for applicable problems. Several factors affect the accuracy of the solutions. To ensure valid results, problems should be modeled so that the flow lines are not constricted into an unnatural path. The flow through each fragment type follows the general shape of the fragment. If several fragments are used to model a relatively small portion of a structure, the flow may be forced into an unnatural path. Modeling of small areas may result in apparent flow where a dead area of virtually no flow exists.

42. Another factor to be considered is the accuracy of the assumption of vertical equipotential lines at the fragment boundaries. Laplace's equation can be satisfied both globally and fragmentally only if the chosen fragment boundaries are, in fact, equipotential lines. This occurs only in simple, symmetric structures, such as a single embedded sheetpile. The greater the deviation from the actual equipotential lines, the greater the degree of error in the solution. For many practical problems, however, the assumption of equipotential lines coincident with fragment boundaries yields reasonable results.

43. Solutions also become less accurate as the number of fragments joined together increases. This results from the inaccuracies in the assumptions of the method.

PART III: INPUT GUIDE

Source of Input

44. Input data may be supplied from a prepared data file or from the user's terminal during execution. If the data are input from the terminal, the user may enter data by using key command words or by following a prompting sequence.

Data Format

45. All input data, whether supplied from a data file or from the terminal, are read in free field format. In addition:

a. Data items must be separated by one or more blank spaces (commas are not allowed as delimiters).

b. Integer numbers must be in nondecimal form.

c. Real numbers may be in either decimal, nondecimal form, or E format.

d. User responses to all requests for program control may be abbreviated by the first letter of the word. For example, in response to the question,
DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO,
the user may enter Y or N .

Data Entry from Terminal

46. There are three ways to enter data from the terminal. They consist of a prompting sequence, a conversational mode, and a nonconversational mode. For the user who is unfamiliar with the program, a prompting sequence is available which will query the user for all necessary data. An explanation of the prompting sequence is found in paragraph 64. For the more experienced user, data may be entered by command words followed by the accompanying data. When using command words the user may select either a conversational or a nonconversational mode of data entry. The conversational mode is for the user who is familiar with the command words but cannot remember the variable list associated with them. This method is explained in paragraph 66. The nonconversational mode is for the experienced user and is explained in paragraph 65.

47. There are several options which may be requested to provide variations on terminal input. The options are explained in paragraphs 70 through 77.

48. For a list of the command words see paragraph 73.

Data Entry from File

49. Data may be entered from a prepared data file. The data file format is the same as the format for the nonconversational mode. The user simply types in a command word and the corresponding data. All lines of input for the data file must begin with a line number.

50. As many problems as desired may be contained in a single data file. The end of data input for each problem is identified by the command word END. After one file is exhausted, the user is given the chance to enter additional runs from either the terminal or from another data file.

51. The command word EXIT may also be used to terminate a run. However, if at any time the command word EXIT is entered, either from a data file or from the terminal, program execution will terminate.

Input Description

General

52. The following is an explanation of the command words, requirements, and variables for data input. If data are input from a data file, then all lines of input must be preceded by a line number.

53. The input information is divided into the following sections:

- a. Title of run.
- b. Units.
- c. Water data.
- d. Fragment data.
- e. Termination.

54. Input data may be entered in any order; however, for some of the available options, certain command words must be entered before the fragment data. These options are explained in paragraphs 70 through 77.

55. Any unit may be specified, but the same unit must be used throughout the problem. The default system of units is in feet, seconds, and pounds.

56. In the following description, [LN] is used to denote the need for a line number when data are entered from a predetermined data file. Single quotes ('NN') denote the use of alphanumeric information; underscore denotes the minimal amount of characters required (FRAGMENT). All command words may be abbreviated to the first four characters.

Input information

57. Title of run (optional).

a. [LN] 'NAME' - title (60 characters or less)

b. Note: If several problems are run and a new title is not input for each problem, the previous title will be used.

58. Units (optional).

a. [LN] 'UNITS' LENGTH TIME

b. Definitions:

'UNIT'	-	command word
LENGTH	-	Two-character description of length used ('FT' is the default value)*
TIME	-	Three-character description of time used ('SEC' is the default value)

c. Note: Only 'FT' and 'M' are valid units of length. If 'FT' is used, then 'LBS' is the default unit of force. If 'M' is used, then 'KG' is the default unit of force.

59. Water description.

a. [LN] 'WATER' K HDWT H FLOW

b. Definitions:

'WATE'	-	command word
K	-	coefficient of permeability
HDWT	-	height of headwater against structure
H	-	change in head (between headwater and tailwater)
FLOW	-	flow direction ('R' - to the right, 'L' - to the left)

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

c. Note: Flow is a one-character description of the direction of flow. 'R' indicates flow to the right, and 'L' indicates flow to the left.

60. Fragment type descriptions.

a. 'FRAGMENT' IFACT DIMENSIONS

b. Definitions:

'FRAG' - command word

IFACT - fragment type

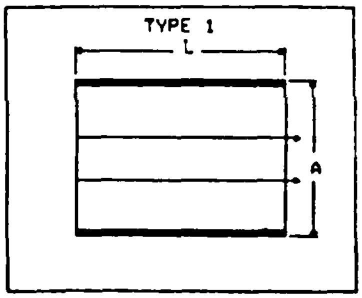
DIMENSIONS - the dimensions required for the particular fragment type chosen (see paragraph 61).

c. Note: A maximum of 10 fragments may be entered. All fragments must be entered in the direction of flow.

61. Summary of fragment data required.

a. TYPE 1.

'FRAG' 1 L A



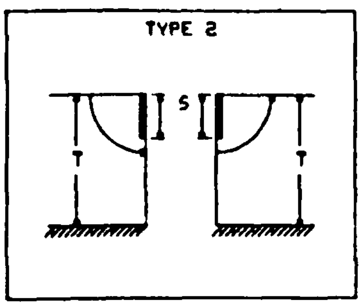
Definitions:

L - The length of the structure

A - The height of the confined flow region

b. TYPE 2

'FRAG' 2 T S



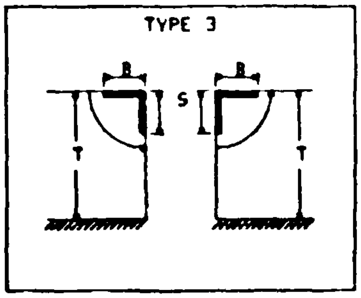
Definitions:

T - The height of the flow region

S - The distance that the structure is embedded into the soil

c. TYPE 3.

'FRAG' 3 B T S



Definitions:

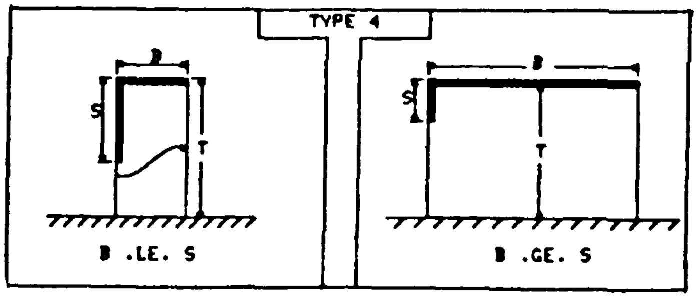
B - The length of the structure resting on the soil

T - The height of the flow region

S - The distance that the structure is embedded into the soil

d. TYPE 4.

'FRAG' 4 B T S FRAGMENT DIRECTION



Definitions:

B - The length of the structure resting on the soil

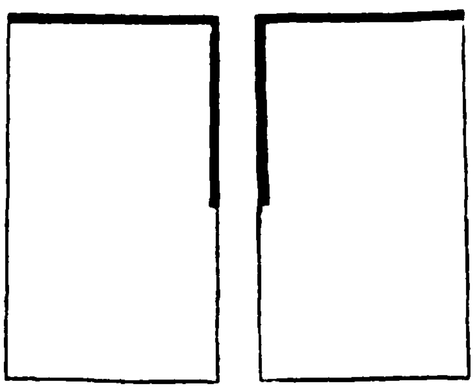
T - The height of the flow region

S - The distance that the structure is embedded into the soil

FRAGMENT DIRECTION - 1 or Ø

Note: Indicate fragment direction by either a 1 or a Ø.

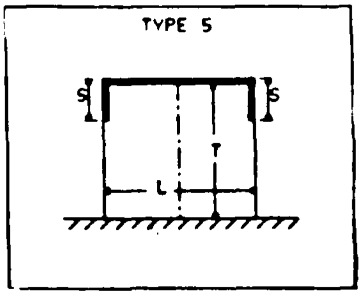
Orientation 1



Orientation Ø

e. TYPE 5.

'FRAG' 5 L T S



Definitions:

L - The length of the structure

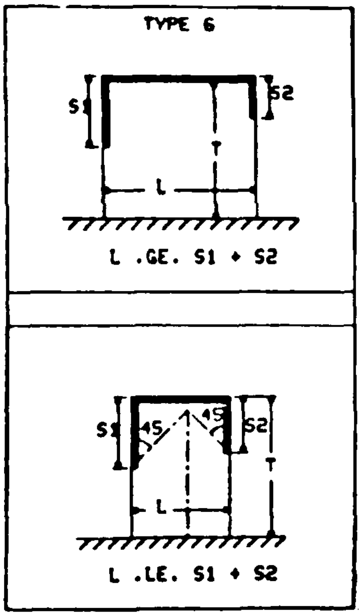
T - The height of the flow region

S - The distance that the structure is embedded into the soil

f. TYPE 6.

'FRAG' 6 L T S1 S2

Note: Regardless of the flow direction, the fragment orientation does not change; S1 is at the left side and S2 is at the right side.



Definitions:

L - The length of the structure

T - The height of the flow region

S_1 - The distance that the structure is embedded into the soil on the left

S_2 - The distance that the structure is embedded into the soil on the right

g. Restrictions: S, S1, or S2 should never be greater than or equal to T.

h. Note: Each fragment is aligned by using the bottom impervious boundary which should always be horizontal. The dimensions S, S1, and S2 may vary on both sides of a sheetpile, and the dimension T may vary from fragment to fragment.

62. Other optional commands.

a. [LN] 'CONVERSATIONAL' - provides conversational mode

b. [LN] 'NONCONVERSATIONAL' - cancels conversational mode

c. [LN] 'MENU' - draws menu

d. [LN] 'GRAPH' - draws graph of each fragment input

e. [LN] 'MEIN' - enters input through menu

f. [LN] 'COMM' - provides list of commands

g. [LN] 'EDIT' - edits input data

h. [LN] 'EXIT' - terminates program execution

i. [LN] 'INFO' - provides information about program

Note: All of the above commands may be entered anywhere prior to the END command. A more thorough explanation of these optional commands is provided later in this report.

63. Termination.

a. 'END' - Identifies the completion of data entry for a particular problem.

Note: As previously mentioned, a predefined data file may contain several problems. The END command must be placed at the end of each individual problem. Once the final problem containing an END command is processed, the user is given the option to make additional runs or terminate the session.

b. 'EXIT' - Identifies the end of a session.

Note: Once the 'EXIT' command is read, the program is immediately terminated. Normally, this command would be preceded by an END command.

Optional Methods of Input

Prompt sequence

64. If the user chooses to enter data from the terminal, then the question

DO YOU WANT TO ENTER DATA USING A PROMPTING SEQUENCE? YES OR NO.

is asked. If prompting is requested, then a sequence of questions will prompt the user for all pertinent data. An example follows:

```
ENTER TITLE (60 CHARACTERS MAXIMUM)
= EXAMPLE PROBLEM

ENTER UNITS,

LENGTH ('FT' OR 'M')        TIME (3 CHARACTERS MAX)
= FT SEC

ENTER WATER DATA,
```

```
PERMEABILITY      HEADWATER    CHANGE IN    FLOW DIRECTION
   (L/T)          HEIGHT (L)   HEAD (L)     (LEFT OR RIGHT)
= .01  20         10  R
```

```
DO YOU WANT TO USE A MENU AND CROSSHAIRS TO INPUT FRAGMENT DATA?
YES OR NO.
= Y
```

NOTE: The sequence may go one of two ways. If the answer is 'YES', then a menu will be drawn, and fragment data may be entered by selecting the desired fragment with the cross hairs. If the answer is 'NO,' then the user will be prompted to input the various fragment types desired. All fragments must be entered in the direction of flow. After all fragment data are input, the user is given the chance to edit the input. The edit sequence is explained under the EDIT option. For more information about the menu and terminal entry refer to the optional command MEIN and the discussion of the conversational mode.

Nonconversational mode

65. If the user decides to enter data from the terminal using the nonconversational mode, then an initial statement is printed providing a brief explanation of the input procedure. The program will then prompt the user, and data may be entered by typing in a command word and any subsequent data. Initially the program is in the nonconversational mode. An example follows:

```
DO YOU WANT TO ENTER DATA USING A PROMPTING SEQUENCE?  YES OR NO.
= N

ENTER DATA USING COMMAND WORDS.  TYPE 'END' TO COMPLETE INPUT.  TYPE
'COMM' FOR A LIST OF COMMANDS.  TYPE 'INFO' FOR MORE INFO.

COMMAND?
= NAME TEST RUN

COMMAND?
= UNITS FT SEC

COMMAND?
= WATE  .01   20  10  R

COMMAND?
= FRAG  2  20  5

COMMAND?
= FRAG  2  20  5

COMMAND?
= END

***** INPUT COMPLETE *****

DO YOU WANT TO CONTINUE THE SOLUTION?  YES OR NO.
= Y
```

The user may continue with the solution of the problem if desired.

Conversational mode

66. When entering data from the terminal, the user may follow a conversational style of input by entering the command CONV. This command may be entered any time a command is requested. The command words requiring additional data may then be typed in by themselves, and the program will respond with a message, like those in the prompting sequence, which will indicate the required data needed for that particular command. An example follows:

```
COMMAND?
= CONV

COMMAND?
= NAME

ENTER TITLE (60 CHARACTERS MAXIMUM)
=TEST RUN

COMMAND?
= WATER

ENTER WATER DATA,

PERMEABILITY      HEADWATER      CHANGE IN      FLOW DIRECTION
   (L/T)          HEIGHT (L)     HEAD (L)       (LEFT OR RIGHT)
= .01  20  10  R

COMMAND?
= FRAGMENT

ENTER THE TYPE OF FRAGMENT 1
= 2

ENTER:  T  S
= 20  5

ENTER THE TYPE OF FRAGMENT 2
= 2

ENTER:  T  S
= 20  5

ENTER THE TYPE OF FRAGMENT 3
= (CR) [If no more fragments are to be entered, then a carriage return
        should be entered to continue.  The user may enter up to
        10 fragments.]

COMMAND?
= END [Indicates that data entry is complete.]
```

The conversational style of input may be switched off at any time by typing in NONC.

Entry from data file

67. Entry from a data file is in the same format as the nonconversational mode except that all lines of input must be preceded by a line number:

```
10    NAME TEST RUN          - Enter title
20    UNIT FT MIN            - Sets units
30    WATE  .01  20  10  R   - Enter water data
40    FRAG  2  20  5         - Enter fragment data
50    FRAG  2  20  5
60    END                    - This command shows that input is
                               complete and directs the program to con-
                               tinue with the solution.
```

Output Options

Modification and rerun capability

68. After output is complete, the question

DO YOU WANT TO MODIFY CURRENT DATA AND RERUN? YES OR NO.

is asked. If the user selects to modify the data, then a sequence exactly like the edit option (paragraphs 74-76) will be followed.

Plotting of water pressures

69. If no errors in the user's data are found, the question,

DO YOU WANT TO PLOT THE WATER PRESSURE? YES OR NO.

is asked. If the user responds with a yes, a plot is drawn which includes a diagram of the structure and the resulting pressure prisms. All pertinent dimensions, water levels, and soil surfaces are shown.

Use of Optional Commands

MEIN command

70. When this command is entered, the program is automatically set for the conversation mode as described in paragraph 66. This command must be entered before fragment data. When the command word FRAG is entered the screen will erase, and a menu of the fragment types will be displayed. A fragment type may then be chosen by positioning the crosshairs within the box containing the fragment desired and entering any character and a carriage return. The needed data for that fragment type will then be requested. After the data are entered, the crosshairs will appear again. When fragment data are complete, enter the character 'E' to return to the command level. After all input is complete, enter the command END to continue with the analysis. An example is shown in Figure 13.

SELECT FRAGMENT WITH X-HAIRS, HIT ANY CHARACTER
AND RETURN. WHEN INPUT IS COMPLETE ENTER
THE CHARACTER 'E'.

ENTER: T S
•20 5

ENTER: T S
•20 5

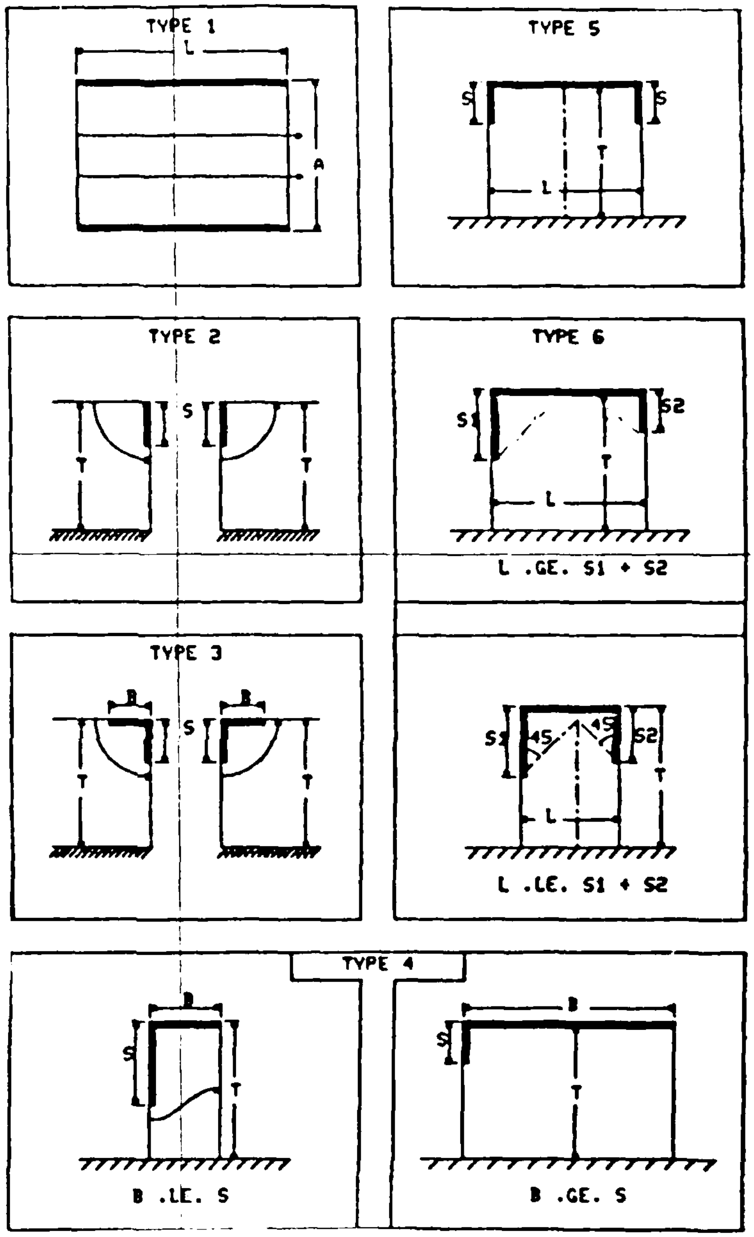


Figure 13. Menu display

MENU command

71. This command will cause the menu to be drawn. It may be used to help the user distinguish the dimensions of the fragments when entering from the terminal, and it may be used later for reference material. Refer to paragraph 70 for an example of the menu.

GRAPH command

72. This command must be entered before fragment data. If this command is used with the command CONV, a graph of the fragment type entered will be drawn, and the required information will be requested. If this command is used without the CONV command, then after a fragment type and data have been entered, a graph of the fragment type will be drawn. Examples of both sequences are shown below.

Sequence using CONV command:

```
COMMAND?
= CONV

COMMAND?
= GRAPH

COMMAND?
= WATER

ENTER WATER DATA,

PERMEABILITY      HEADWATER      CHANGE IN      FLOW DIRECTION
   (L/T)          HEIGHT (L)     HEAD (L)       (LEFT OR RIGHT)
= .01  20  10  R
```

Note: If a prompt for only the fragment data is desired, then the CONV command may be entered after all other data have been entered but before the FRAGMENT command.

```
COMMAND?
= FRAG

ENTER THE TYPE OF FRAGMENT 1
=.2
```

Note: The screen is erased, fragment type 2 is drawn, and the required data are requested (see Figure 14).

```
ENTER T, S
= 20  5

ENTER THE TYPE OF FRAGMENT 2
= [CARRIAGE RETURN]

COMMAND?
=
```

ENTER: T S

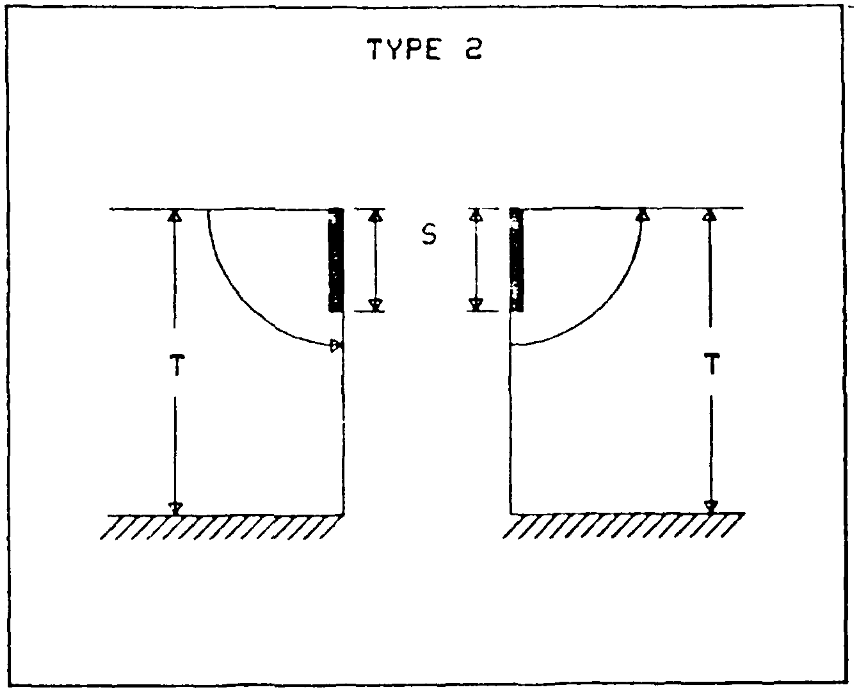


Figure 14. Computer response

Sequence without using CONV command:

COMMAND?
= GRAPH

COMMAND?
= WATE .01 20 10 R

COMMAND?
= FRAG 2 20 5

Note: The screen is erased and fragment type 2 is drawn.

COMMAND

73. After the user enters this command, a list of the command words will appear at the terminal. It may be entered any time a command is requested. Following is a list of all the commands:

COMMANDS:

CONV - PROVIDE CONVERSATIONAL STYLE OF INPUT
NONC - CANCEL CONVERSATIONAL STYLE OF INPUT
MENU - DRAW MENU
GRAP - DRAW GRAPH OF FRAGMENT TYPE AND INPUT DATA
MEIN - DRAW MENU AND INPUT FROM CROSSHAIRS

FRAG - ENTER FRAGMENT TYPE AND DATA
WATE - ENTER WATER DATA
END - INPUT COMPLETE
COMM - PRINT LIST OF COMMANDS
EDIT - EDIT INPUT
EXIT - EXIT PROGRAM
UNIT - ENTER LENGTH AND TIME UNITS
INFO - PROVIDE INFORMATION ABOUT PROGRAM

EDIT command

74. Entering this command invokes a sequence whereby the input data may be changed. It is the same sequence used in the Prompting Sequence and the Modification of Data Options. If data are being entered from the terminal, the EDIT command may be given once the input is finished. Input is assumed to be complete upon completion of the edit sequence.

75. The edit sequence is in four sections: the title, the units, the water data, and the fragment data. Any or all of these sections may be edited. In addition, the fragment section has several commands to change fragment data. They are as follows:

a. CHANGE - This command is used to change fragment types. The new data needed will be requested.

b. DELETE - This command will delete a specified fragment.

c. ADD - This command will add a fragment to the existing arrangement of fragments at the location specified.

The CHANGE, DELETE, and ADD commands are set up in the following manner:

OPTION	A	B
CHANGE	FRAGMENT NO.	FRAGMENT TYPE
DELETE	FRAGMENT NO.	
ADD	FRAGMENT NO.	FRAGMENT TYPE

The user should enter

OPTION A B

For example,

CHANGE 3 2

DELETE 4

76. A detailed description of each command follows:

a. CHANGE command.

OPTION = CHANGE

A = Number of the fragment to be changed.

B = New fragment type desired.

After this command is entered the information required for the new fragment type will be requested.

b. ADD command.

OPTION = ADD

A - The number of the fragment which will precede the fragment to be added.

B - The fragment type desired.

'A' may be [illegible] fragment number.

Enter [illegible] fragment number one.

c. DELETE command.

OPTION = DELETE

A - The number of the fragment to be deleted.

77. The fragment [illegible] resequenced [illegible] use of the ADD or DELETE command. To check the numbering of the current fragments use the LIST command.

78. There are several other commands to assist the user. They are:

a. LIST - This command lists the current arrangement of fragments entered.

b. HELP - This command gives a brief description of all the other commands.

(1) HELP CHANGE - gives a detailed description of the CHANGE command.

(2) HELP DELETE - gives a detailed description of the DELETE command.

(3) HELP ADD - gives a detailed description of the ADD command.

[illegible]

General

79. The program [illegible] data to ensure that all fragments are [illegible] tailwater elevation does not fall below [illegible] exceeded, an error message [illegible] their form factors. The edit [illegible] corrections to the data.

Restrictions on Fragment [illegible]

80. [illegible] entry of fragment data. Fragment [illegible] flow. Further, fragment type [illegible] Fragment types 1,

4, 5, and 6 can only be located within the structure; they cannot act as entry or exit fragments. Finally, a maximum of 10 fragments may be entered for each problem.

Notes on error messages

81. In addition to the error messages previously discussed, other error messages may be encountered in the execution of the program. Two example conditions which will cause error messages are: (a) insufficient number of values entered for the specified command word and (b) an incorrect parameter detected in the data list.

82. To correct either of the above errors while using the prompt sequence or the conversational mode, the user is required only to re-enter the variable list. The user will not be allowed to continue until the required data are entered.

83. In the nonconversational mode or while entering data from a data file, the user must re-enter the command word along with the required data. The user may select to re-enter the command in which the error was detected or continue with another command. The only exception to this rule occurs when data are specifically asked for again.

84. In addition, if entry is from a file and an error message is encountered, several options may be exercised: (a) the particular command may be corrected, (b) another command may be entered, or (c) a carriage return may be entered which will result in the next line of data being read from the file and the incorrect line being ignored.

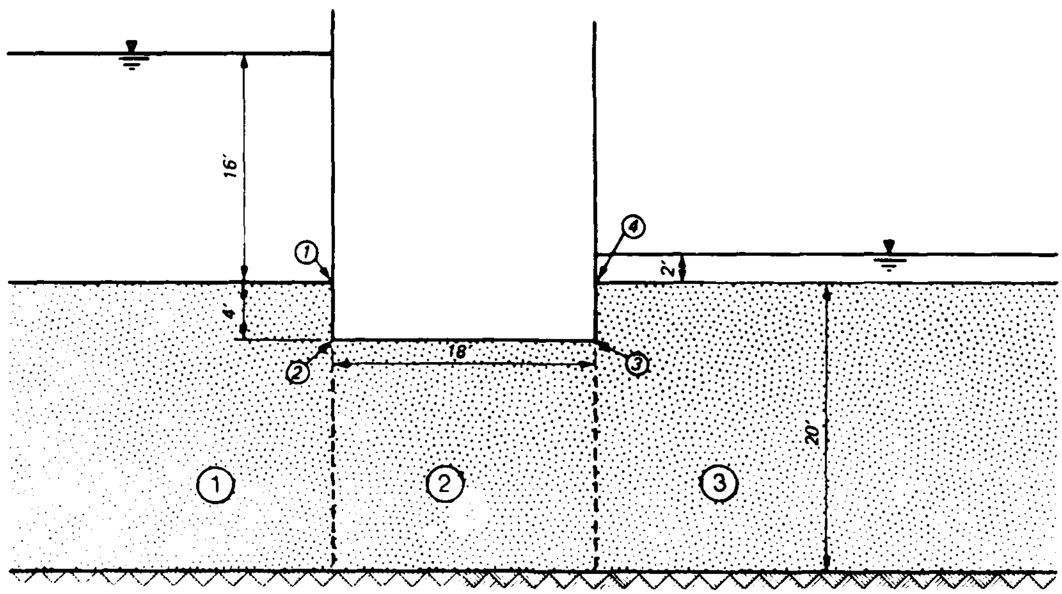
APPENDIX A: EXAMPLE COMPUTER RUNS AND HAND VERIFICATIONS

1. This appendix contains example runs and hand computations. Solutions are provided for typical problems that can be analyzed by the method of fragments. The examples are intended to show how the various fragment types can be utilized to model a flow region and how the form factor for each fragment type is calculated. The hand computations are provided to verify the results from CFRAG.

2. In the diagrams accompanying each problem, the different fragments are identified by large circled numbers, and points of pressure calculations are identified by small circled numbers.

3. To analyze this structure, the user must divide the flow region shown into three fragments. The analysis is performed from left to right corresponding to the direction of flow.

Example A1: Flow Under Simple Structure Without Sheetpiles



Fragment number 1

4. Fragment number 1 is an entrance condition and is a type 2 fragment.

$$S = 4$$
$$T = 20$$
$$\Phi = \frac{K}{K'} \text{ where } m = \sin \frac{\pi S}{2T}$$

$$m = \sin \frac{\pi(4)}{2(20)} = 0.3090$$

$$m^2 = 0.0955$$

$$(m')^2 = 1 - m^2 = 0.9045$$

From tabulated values of elliptic integrals of the first kind,

$$K = 1.610$$
$$K' = 2.600$$
$$\frac{K}{K'} = 0.619$$
$$\Phi = 0.619$$

Fragment number 2

5. Fragment number 2 is a type 1 fragment.

$$L = 18$$
$$A = 16$$

$$\Phi = \frac{L}{A}$$

$$= \frac{18}{16}$$

$$= 1.125$$

Fragment number 3

6. Fragment number 3 is a type 2 fragment and is an exit condition.

$$S = 4$$
$$T = 2^{\frown}$$

$$\Phi = \frac{K}{K'} \quad \text{where } m = \sin \frac{\pi S}{2T}$$

7. This fragment is identical with fragment number 1; therefore, the form factor is also the same.

$\Phi = 0.619$

<u>Head loss calculations</u>

8. Head loss calculations are as follows:

$\Sigma\Phi = 2(0.619) + 1.125 = 2.363$

$$h_m = \frac{h\Phi m}{\Sigma\Phi}$$

$$h_1 = \frac{14(0.619)}{2.363} = 3.67$$

$$h_2 = \frac{14(1.125)}{2.363} = 6.67$$

$$h_3 = 3.67$$

Total head loss = 3.67 + 6.67 + 3.67 = 14.0 ft

<u>Pressure calculations</u>

9. Pressure loss calculations are as follows:

$$P = \left[\left| Z_2 \right| - h_L \right] \gamma_w$$

$P_1 = 16(62.4) = 998.4$ psf

$P_2 = (20 - 3.67)\ 62.4 = 1019.0$ psf

$P_3 = (20 - (3.67 + 6.67))\ 62.4 = 603$ psf

$P_4 = (16 - 14)\ 62.4 = 124.8$ psf

<u>Total flow calculation</u>

$$q = \frac{kh}{\Sigma\Phi}$$

$$q = \frac{14.4(14.0)}{2.363} = 85.32 \text{ ft}^3\text{/day per foot of width}$$

<u>Exit gradient calculation</u>

$$I_E = \frac{h_3 \pi}{2KTm} = \frac{3.67(\pi)}{2(1.610)(20)(0.3090)} = 0.579$$

```
CONFINED FLOW - METHOD OF FRAGMENTS
TIME  16 36 56                        DATE  8/ 8/83

TITLE - Simple Structure without Sheetpiles
Q =   85 2829 (FT**2/DAY)
K =   14 4000 (FT/DAY)
Q/K =    5 92 (FT)
TOTAL HEAD LOSS =   14 00 (FT)
FRAG FRAG                                                          FORM    HEAD
NO   TYPE     L        A        B        T        S1       S2     FACTOR   LOSS
             (FT)     (FT)     (FT)     (FT)     (FT)     (FT)             (FT)
---------------------------------------------------------------------------------
 1    2                                 20.00    4 00              0.62    3 67
 2    1     18.00    16.00                                         1 13    6 66
 3    2                                 20.00    4.00              0.62    3.67
EXIT GRADIENT =  0.5790


                    RESULTANT FORCES ON STRUCTURE
          LATERAL FORCE      UPLIFT FORCE       LATERAL FORCE
          HEADWATER SIDE                        TAILWATER SIDE
              (LBS)             (LBS)               (LBS)

             12022.2           14601 6             1581 0


DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO.
=Y
```

Figure A1. Program output for Example A1

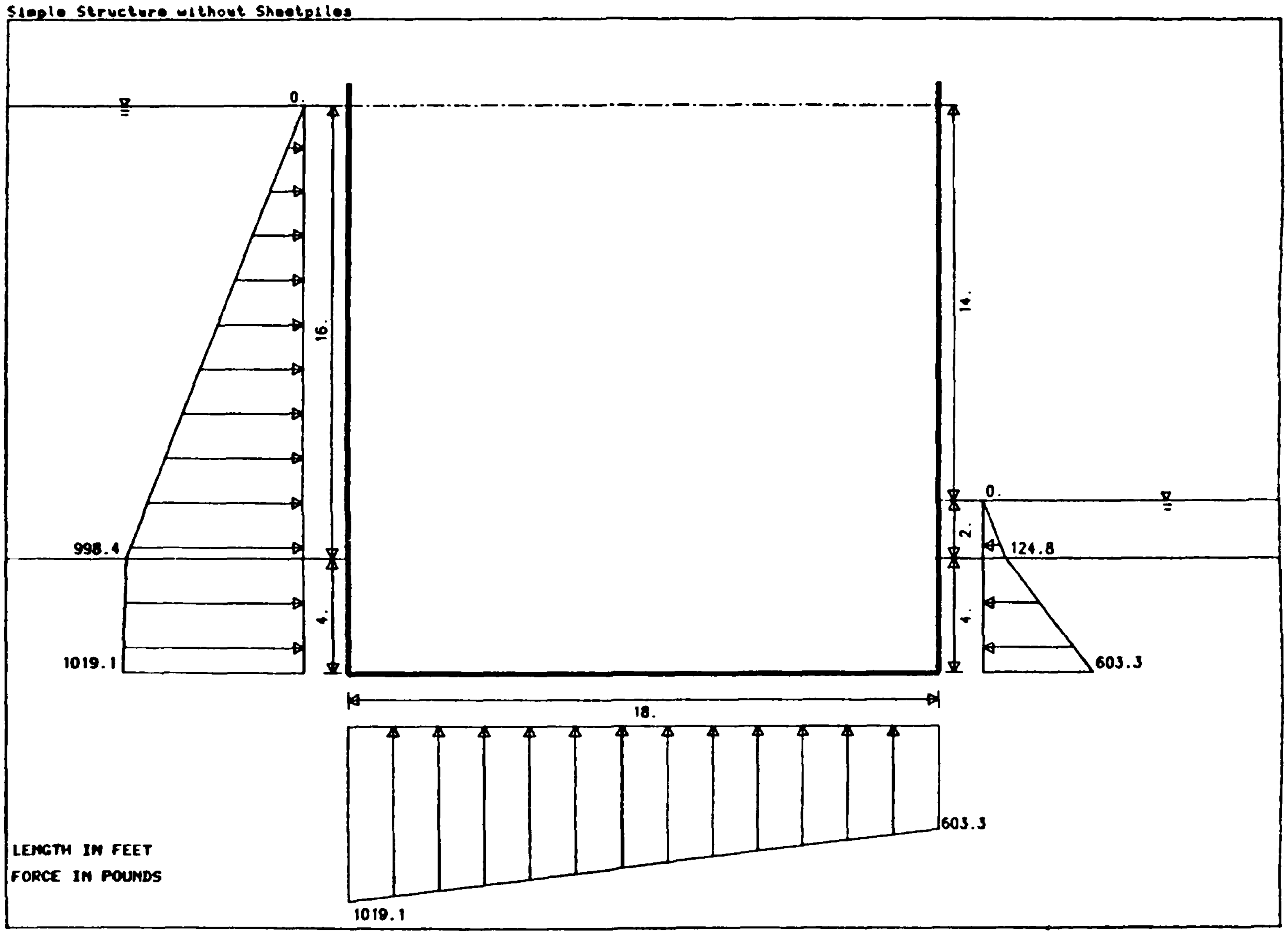
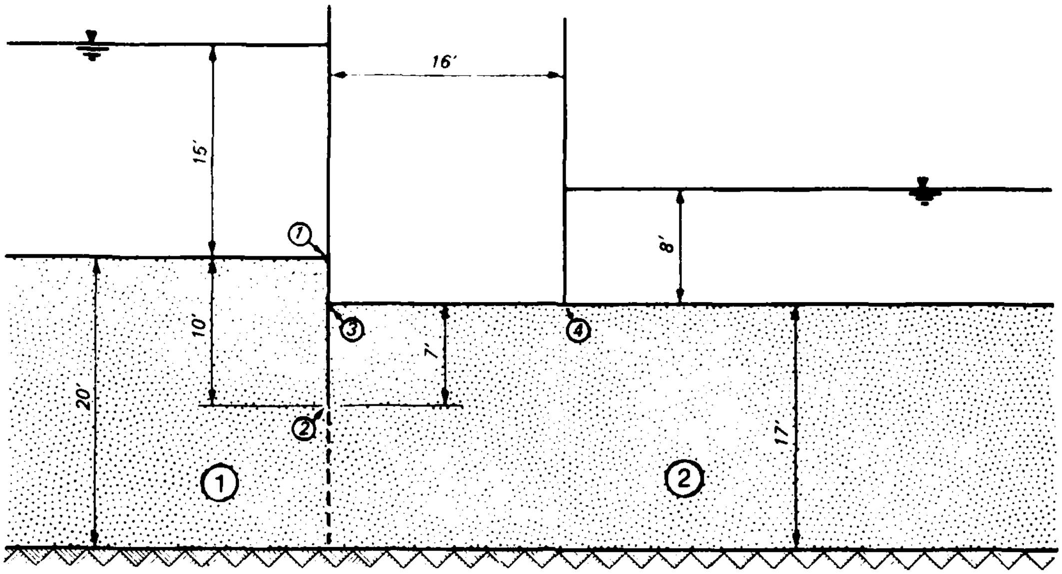


Figure A2. Plot of pressures for Example A1

Example A2. Weir with Upstream Sheetpile

10. To analyze this structure, the user must divide the flow region shown into two fragments. The analysis is performed proceeding from left to right.



Fragment number 1

11. Fragment number 1 is a type 2 fragment and an entrance condition.

$$S = 10$$

$$T = 20$$

$$\Phi = \frac{K}{K'} \text{ where } m = \sin \frac{\pi S}{2T}$$

$$m = \sin\left(\frac{\pi(10)}{2(20)}\right) = 0.7071$$

$m^2 = 0.50$

$m'^2 = 1 - m^2 = 0.50$

From tabulated values of elliptic integrals of the first kind,

$K = 1.854$

$K' = 1.854$

$\frac{K}{K'} = 1.000$

$\Phi = 1.000$

Fragment number 2

12. Fragment number 2 is a type 3 fragment and an exit condition.

$$S = 7$$
$$b = 16$$
$$T = 17$$

$$\Phi = \frac{K}{K'} \text{ where } m = \cos\frac{\pi S}{2T}\sqrt{\tan h^2 \frac{\pi b}{2T} + \tan^2 \frac{\pi S}{2T}}$$

$$m = \cos\left(\frac{\pi(7)}{2(17)}\right)\sqrt{\tan h^2\left(\frac{\pi(16)}{(2(17)}\right) + \tan^2\left(\frac{\pi(7)}{2(17)}\right)}$$

$m = 0.9383$

$m^2 = 0.8803$

From tabulated values of elliptic integrals of the first kind,

$\frac{K}{K'} = 1.54$

$\Phi = 1.54$

Head loss calculations

13. Head loss calculations are as follows:

$\Sigma\Phi = 1.00 + 1.54 = 2.54$

$h_m = \frac{h\Phi m}{\Sigma\Phi}$

$h_1 = \frac{10(1.00)}{2.54} = 3.94$ ft

$h_2 = \frac{10(1.54)}{2.54} = 6.06$ ft

Head loss gradient in fragment 2,

$\text{Gradient}_2 = \frac{6.06}{7 + 16} = 0.2635$

Total head loss = 3.94 + 6.06 = 10.0 ft

Pressure calculations

14. Pressure loss calculations are as follows:

$P = \left[\left|Z_2\right| - h_L\right] \gamma_w$

$P_1 = 15(62.4) = 936$ psf

$P_2 = (25 - 3.94)\ 62.4 = 1314.1$ psf

$P_3 = [18 - (3.94 + 0.2635(7))]\ 62.4 = 762.5$ psf

$P_4 = (18 - (3.94 + 6.06))\ 62.4 = 499.2$ psf

Total flow calculation

$$q = \frac{kh}{\Sigma\Phi}$$

$$q = \frac{14.4(10.0)}{2.54} = 56.69 \text{ ft}^3\text{/day per foot of width}$$

Exit gradient calculation

Since the exit fragment is a type 3 fragment, there is no embedment on the tailwater side. The exit gradient for this case is infinite.

CONFINED FLOW - METHOD OF FRAGMENTS

TIME 16:38:42 DATE: 8/ 8/83

TITLE - Weir with Upstream Sheetpile

Q = 56.7307 (FT**2/DAY)

K = 14.4000 (FT/DAY)

Q/K = 3.94 (FT)

TOTAL HEAD LOSS = 10.00 (FT)

FRAG NO	FRAG TYPE	L (FT)	A (FT)	B (FT)	T (FT)	S1 (FT)	S2 (FT)	FORM FACTOR	HEAD LOSS (FT)
1	2				20.00	10.00		1.00	3.94
2	3			16.00	17.00	7.00		1.54	6.06

WARNING - THERE IS NO EMBEDMENT ON THE TAILWATER SIDE.
EXIT GRADIENT IS INFINITE AND PIPING MAY OCCUR.

RESULTANT FORCES ON STRUCTURE

LATERAL FORCE HEADWATER SIDE (LBS)	UPLIFT FORCE (LBS)	LATERAL FORCE TAILWATER SIDE (LBS)
18270.8	10091.8	9264.3

DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO
=Y

Figure A3. Program output for Example A2

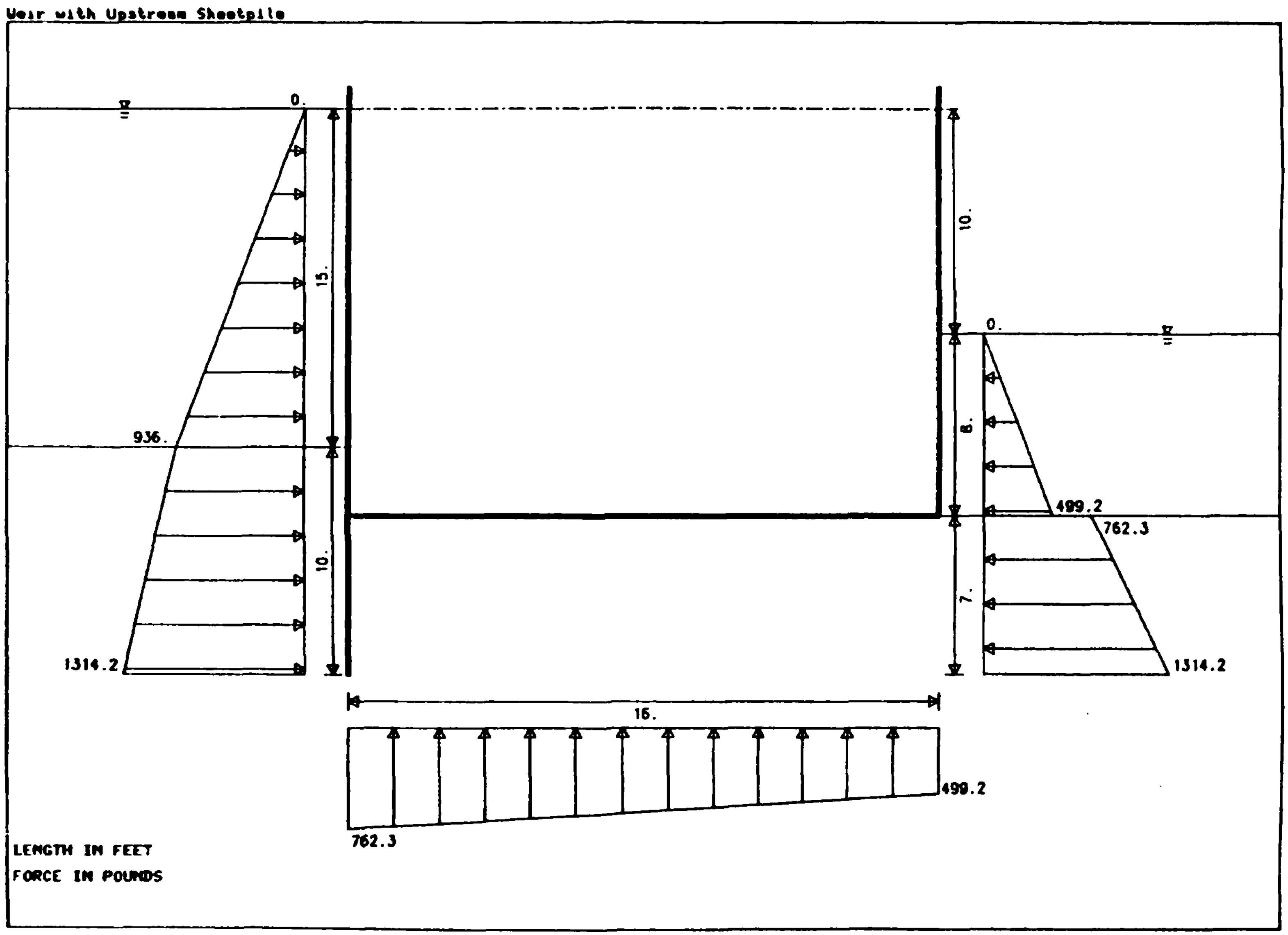
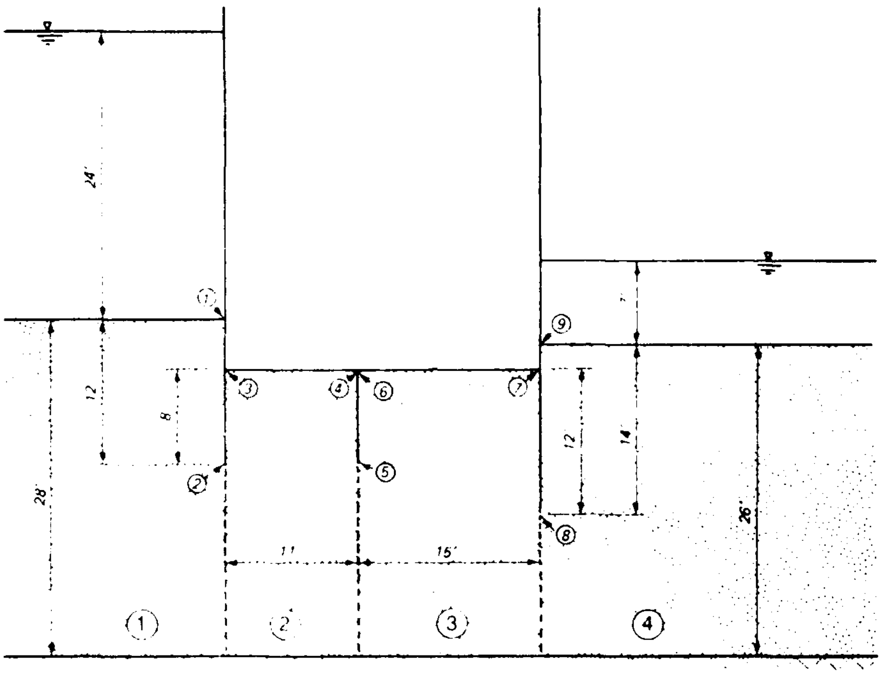


Figure A4. Plot of pressure for Example A2

15. To analyze this structure, the user divides the flow region shown into four fragments. The analysis is performed from left to right.



Fragment number 1

16. Fragment number 1 is an entrance condition and a type 2 fragment.

$$S = 12$$

$$T = 28$$

$$\Phi = \frac{K}{K'}, \text{ where } m = \sin \frac{\pi S}{2T}$$

$$m = \sin\left(\frac{\pi(12)}{2(28)}\right) = 0.6235$$

$$m^2 = 0.3887$$

From tabulated values of elliptic integrals of the first kind,

$$\frac{K}{K'} = 0.902$$

$$\Phi = 0.902$$

Fragment number 2

17. Fragment number 2 is a type 5 fragment.

$$S = 8$$
$$L = 11$$
$$T = 24$$
$$a = 16$$

$2S = 2(8) = 16$

Since $L < 2S$,

$$\Phi = 2 \ln \left(1 + \frac{L}{2a}\right)$$
$$= 2 \ln \left(1 + \frac{11}{2(16)}\right)$$
$$= 0.591$$

Fragment number 3

18. Fragment number 3 is a type 6 fragment.

$$S' = 8$$
$$S'' = 12$$
$$L = 15$$
$$T = 24$$
$$a' = 6$$
$$a'' = 12$$

$S' + S'' = 8 + 12 = 20$

Since $L < S' + S''$,

$$\Phi = \ln \left[\left(1 + \frac{b'}{a'}\right) \left(1 + \frac{b''}{a''}\right)\right]$$

where: $$b' = \frac{L + (S' - S'')}{2}$$

$$b'' = \frac{L - (S' - S'')}{2}$$

$$b' = \frac{15 + (8 - 12)}{2} = 5.5$$

$$b'' = \frac{15 - (8 - 12)}{2} = 9.5$$

$$\Phi = \ln\left[\left(1 + \frac{5.5}{16}\right)\left(1 + \frac{9.5}{12}\right)\right]$$

$$= 0.879$$

<u>Fragment number 4</u>

19. Fragment number 4 is an exit condition and is a type 2 fragment.

$$S = 14$$

$$T = 26$$

$$\Phi = \frac{K}{K'}, \text{ where } m = \sin\frac{\pi S}{2T}$$

$$m = \sin\left(\frac{\pi(14)}{2(26)}\right) = 0.7485$$

$$m^2 = 0.5603$$

$$m'^2 = 1 - m^2 = 0.4397$$

From tabulated values of elliptic integrals of the first kind,

$$K = 1.908$$

$$K' = 1.806$$

$$\frac{K}{K'} = 1.06$$

$$\Phi = 1.06$$

<u>Head loss calculations</u>

20. Head loss calculations are as follows:

$$\Sigma\Phi = 0.962 + 0.591 + 0.879 + 1.06 = 3.432$$

$$h_m = \frac{h\Phi_m}{\Sigma\Phi}$$

$$h_1 = \frac{19(.962)}{3.432} = 5.0$$

$$h_2 = \frac{19(.591)}{3.432} = 3.27 \qquad \text{Gradient}_2 = \frac{3.27}{8 + 8 + 11} = 0.1211$$

$$h_3 = \frac{19(.879)}{3.432} = 4.87 \qquad \text{Gradient}_3 = \frac{4.87}{8 + 12 + 15} = 0.1391$$

$$h_4 = \frac{19(1.06)}{3.432} = 5.87$$

Total head loss = 5.0 + 3.27 + 4.87 + 5.87 = 19.0 ft

Pressure calculations

21. Pressure loss calculations are as follows:

$$P = \left[\left| Z_2 \right| - h_L \right] \gamma_w$$

$$P_1 = 24(62.4) = 1497.6 \text{ psf}$$

$$P_2 = (36 - 5.0)\ 62.4 = 1934.4 \text{ psf}$$

$$P_3 = [28 - (5.0 + 0.1211(8.0))]\ 62.4 = 1374.7 \text{ psf}$$

$$P_4 = [28 - (5 + 0.1211(19))]\ 62.4 = 1291.6 \text{ psf}$$

$$P_5 = [36 - (5 + 3.27)]\ 62.4 = 1730.4 \text{ psf}$$

$$P_6 = [28 - (5 + 3.37 + .1391(8))]\ 62.4 = 1161.7 \text{ psf}$$

$$P_7 = [28 - (5 + 3.27 + .1391(23))]\ 62.4 = 1031.5 \text{ psf}$$

$$P_8 = [40 - (5 + 3.27 + 4.87)]\ 62.4 = 1676.0 \text{ psf}$$

$$P_9 = 7(62.4) = 436.8 \text{ psf}$$

Total flow calculation

$$q = \frac{kh}{\Sigma\Phi}$$

$$q = \frac{14.4(19.0)}{3.432} = 79.72 \text{ ft}^3\text{/day per foot of width}$$

Exit gradient calculation

$$I_E = \frac{h_4 \pi}{2KTm} = \frac{5.87(\pi)}{2(1.908)(26)(0.7485)} = 0.248$$

```
CONFINED FLOW - METHOD OF FRAGMENTS
TIME  16 43 41                         DATE  8/ 8/83

TITLE - Dam with Multiple Sheetpiles
Q =    79 8026 (FT**2/DAY)
K =    14 4000 (FT/DAY)
Q/K =      5 54 (FT)
TOTAL HEAD LOSS =    19 00 (FT)
```

FRAG NO	FRAG TYPE	L (FT)	A (FT)	B (FT)	T (FT)	S1 (FT)	S2 (FT)	FORM FACTOR	HEAD LOSS (FT)
1	2				28 00	12 00		0 90	5 00
2	5	11 00			24 00	8 00		0 59	3 27
3	6	15 00			24 00	8 00	12 00	0 88	4 87
4	2				26 00	14 00		1 06	5 86

```
EXIT GRADIENT =  0 2477
```

RESULTANT FORCES ON STRUCTURE

LATERAL FORCE HEADWATER SIDE (LBS)	UPLIFT FORCE (LBS)	LATERAL FORCE TAILWATER SIDE (LBS)
38563 5	31109 1	16317.5

```
DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO
=Y
```

[illegible] gram output for Example A3

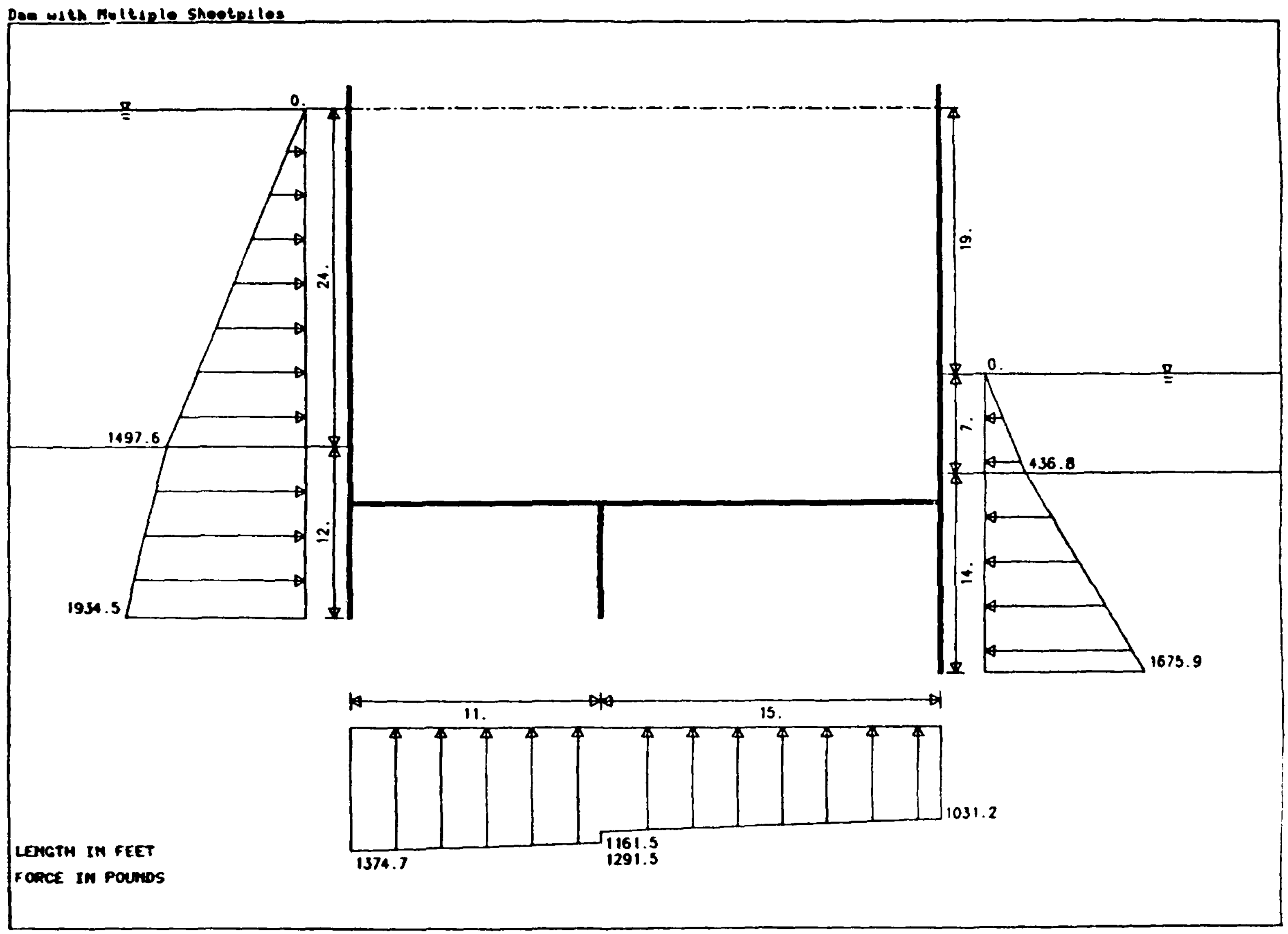
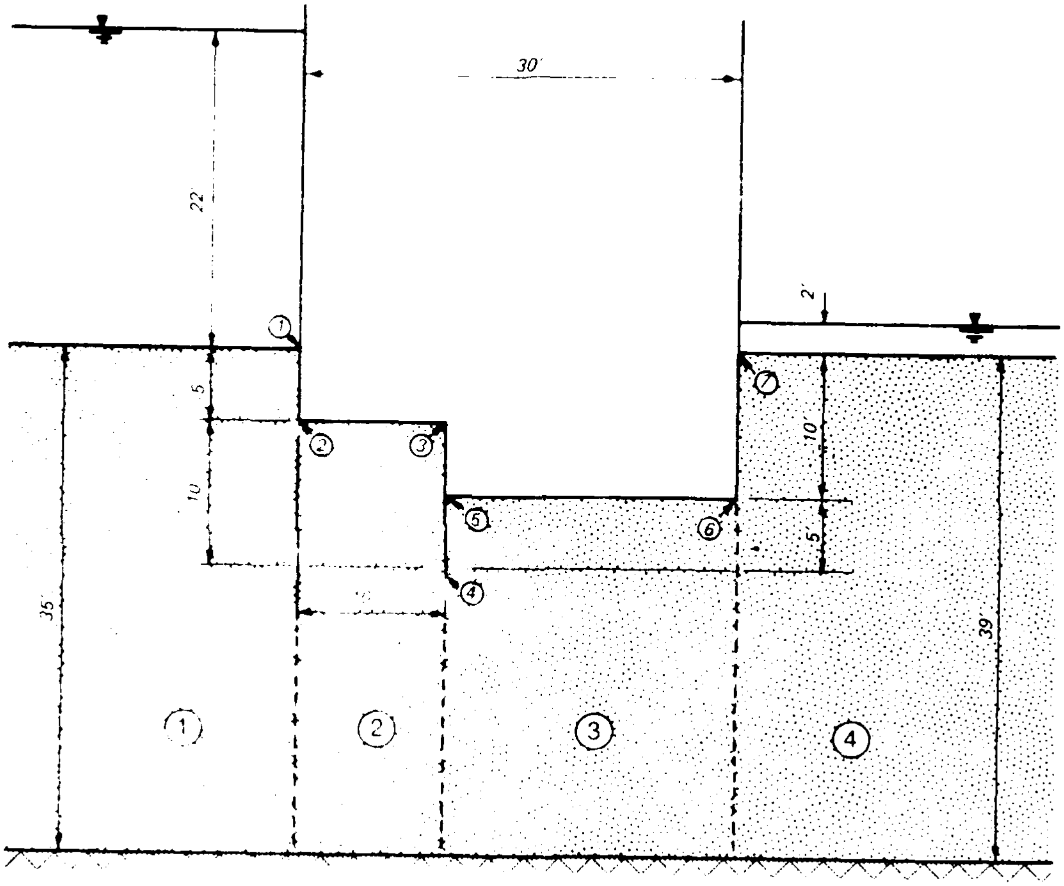


Figure A6. Plot of pressures for Example A3

Example A4. Structure with a Sheetpile and a "Step-down" in the Base

22. To analyze this structure, the user must divide the flow region shown into four fragments. The analysis is performed from left to right.



Fragment number [illegible]

23. Fragment number [illegible] an entrance condition and is a type 2 fragment.

$$[illegible] \frac{K}{K'}, \text{ where } m = \sin \frac{\pi S}{2T}$$

$$m = \sin\left(\frac{\pi(5)}{2(35)}\right) = 0.2225$$

$$m^2 = 0.0495$$

From tabulated values of elliptic integrals of the first kind,

$$\frac{K}{K'} = 0.546$$

$$\Phi = 0.546$$

Fragment number 2

24. Fragment number 2 is a type 4 fragment.

$$S = 10$$

$$a = 20$$

$$b = 10$$

$$T = 30$$

Since S = b, either formula will work.

$$\Phi = \ln\left(1 + \frac{b}{a}\right)$$

$$= \ln\left(1 + \frac{10}{20}\right)$$

$$= 0.405$$

Fragment number 3

25. Fragment number 3 is a type 4 fragment.

$$S = 5$$

$$a = 20$$

$$b = 20$$

$$T = 25$$

Since b > S,

$$\Phi = \ln\left(1 + \frac{S}{a}\right) + \frac{b - S}{T}$$

$$\Phi = \ln\left(1 + \frac{5}{20}\right) + \frac{20 - 5}{25}$$

$$= 0.823$$

Fragment number 4

26. Fragment number 4 is an exit condition and a type 2 fragment.

$$S = 10$$

$$T = 35$$

$$\Phi = \frac{K}{K'} \text{ where } m = \sin \frac{\pi S}{2T}$$

$m = \sin \left(\frac{\pi(10)}{2(35)}\right) = 0.4339$

$m^2 = 0.1883$

$m'^2 = 1 - m^2 = 0.8117$

From tabulated values of elliptic integrals of the first kind,

$K = 1.654$

$K' = 2.285$

$\frac{K}{K'} = 0.724$

$\Phi = 0.724$

Head loss calculations

27. Head loss calculations are as follows:

$\Sigma\Phi = 0.546 + 0.405 + 0.823 + 0.724 = 2.498$

$h_m = \frac{h\Phi m}{\Sigma\Phi}$

$h_1 = \frac{20(0.546)}{2.498} = 4.37$

$h_2 = \frac{20(0.405)}{2.498} = 3.24$ Gradient$_2 = \frac{3.24}{10 + 10} = 0.1620$

$h_3 = \frac{20(0.823)}{2.498} = 6.59$ Gradient$_3 = \frac{6.59}{5 + 20} = 0.2636$

$h_4 = \frac{20(0.724)}{2.498} = 5.80$

Total head loss = 4.37 + 3.24 + 6.59 + 5.80 = 20.0 ft

Pressure calculations

28. Pressure loss calculations are as follows:

$P = \left[\left| Z_2 \right| - h_L \right] \gamma_w$

$P_1 = 22(62.4) = 1372.8$ psf

$P_2 = (27 - 4.37)\ 62.4 = 1412.1$ psf

$P_3 = [27 - (4.37 + 0.1620(10))]\ 62.4 = 1311.0$ psf

$P_4 = (37 - (4.37 + 3.24))\ 62.4 = 1833.9$ psf

$P_5 = [32 - (4.37 + 3.24 + .2636(5))]\ 62.4 = 1439.7$ psf

$P_6 = [32 - (4.37 + 3.24 + 6.59)]\ 62.4 = 1110.7$ psf

$P_7 = 2(62.4) = 124.8$ psf

Total flow calculation

$$q = \frac{kh}{\Sigma\Phi}$$

$$q = \frac{14.4(20.0)}{2.498} = 115.29 \text{ ft}^3\text{/day per foot of width}$$

Exit gradient calculation

$$I_E = \frac{h_4\pi}{2KTm} = \frac{5.80(\pi)}{2(1.654)(35)(0.4339)} = 0.363$$

```
CONFINED FLOW - METHOD OF FRAGMENTS
TIME: 16:41:48                          DATE:  8/ 8/83

TITLE - Dam with Interior Sheetpile with Non-Uniform Base
Q =  115.2679 (FT**2/DAY)
K =   14.4000 (FT/DAY)
Q/K =     8.00 (FT)
TOTAL HEAD LOSS =   20.00 (FT)
```

FRAG NO.	FRAG TYPE	L (FT)	A (FT)	B (FT)	T (FT)	S1 (FT)	S2 (FT)	FORM FACTOR	HEAD LOSS (FT)
1	2				35.00	5.00		0.55	4.37
2	4			10.00	30.00	10.00		0.41	3.25
3	4			20.00	25.00	5.00		0.82	6.59
4	2				35.00	10.00		0.72	5.79

EXIT GRADIENT = 0.3624

RESULTANT FORCES ON STRUCTURE

LATERAL FORCE HEADWATER SIDE (LBS)	UPLIFT FORCE (LBS)	LATERAL FORCE TAILWATER SIDE (LBS)
37784.2	39110.1	14482.4

```
DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO
=Y
```

Figure A7. Program output for Example A4

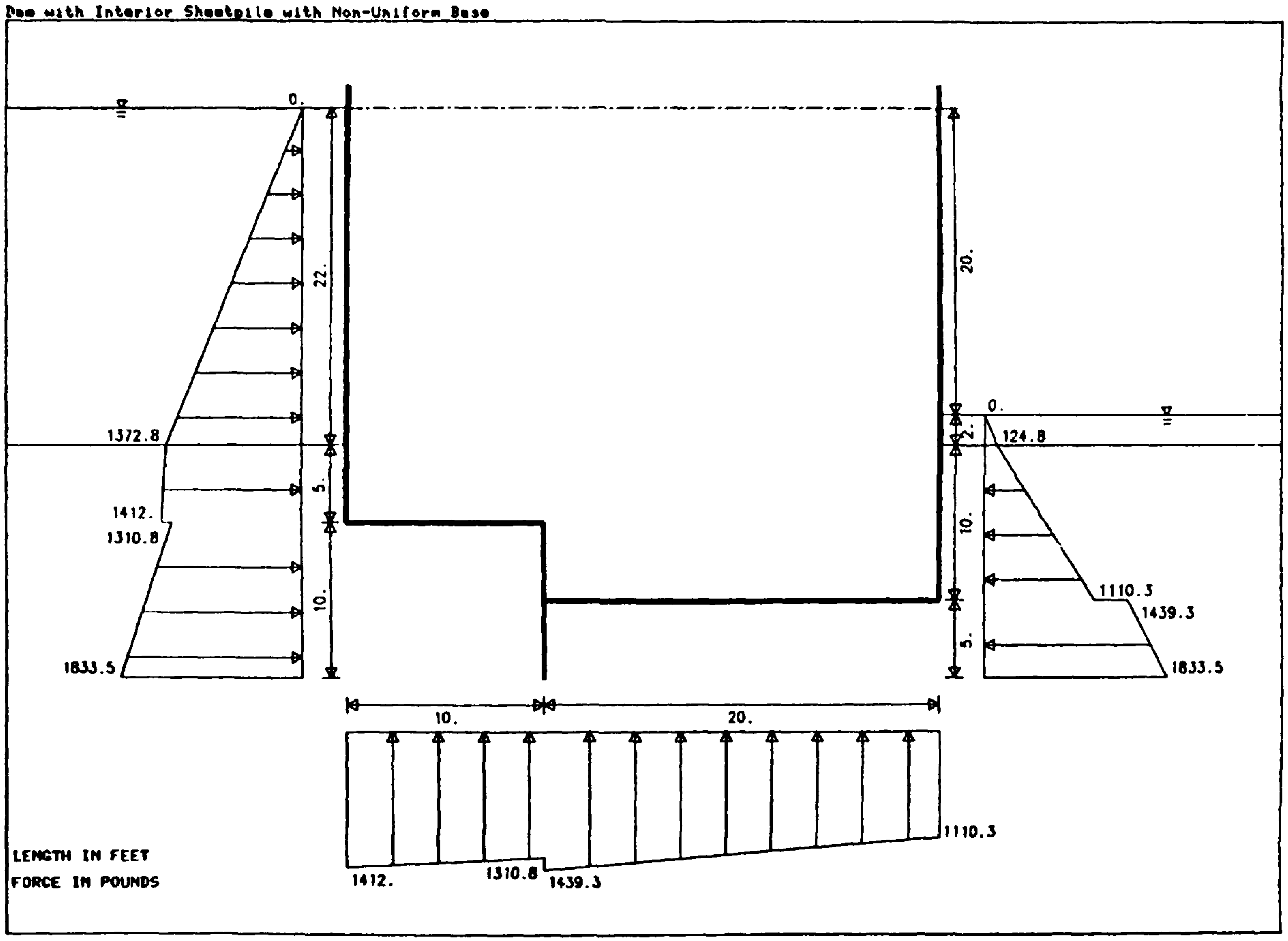


Figure A8. Plot of pressures for Example A4

APPENDIX B: COMPARISON OF ANALYSIS METHODS

1. In this appendix, examples are presented to compare the method of fragments with other commonly used methods of analyzing seepage. Included in the comparison are solutions using the method of creep, a finite element method, and flownets. The finite element program is titled SEEPKG, and it was written by Mr. Fred Tracy, ADP Center, Waterways Experiment Station. The program is [illegible] in the CORPS Library as X8202.

2. The total uplift force and the location of the resultant as well as the total flow and exit gradient are compared for each problem. A plot of the pressures obtained by each method is included as a visual aid in the comparison.

Example B1: Single Sheetpile

3. The problem illustrated in Figure B1 is to analyze seepage around a single sheetpile.

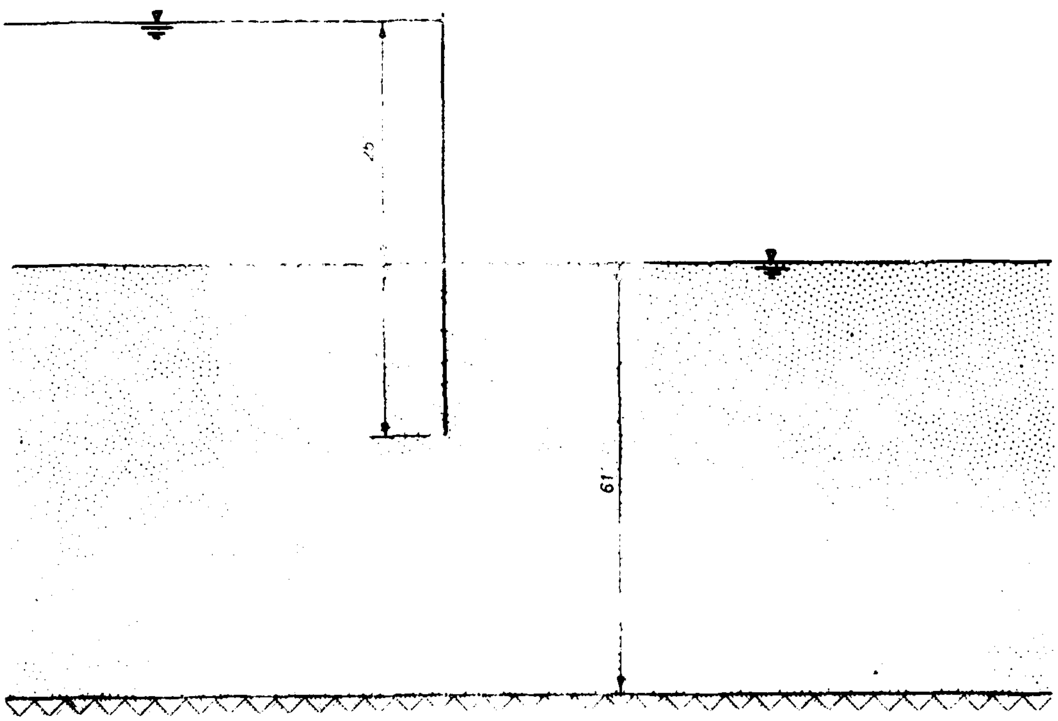


Figure B1. Single sheetpile

4. The given problem, modeled by two type 2 fragments, may be solved by the method of fragments as shown in Figure B1a. The results from CFRAG are shown in Figures B1b and B1c.

5. The solution of the problem by a flownet is shown in Figure B1d. The grid used in the finite element analysis is shown in Figure B1e. The sheetpile modeled by a 1-ft-wide gap is shown in Figure B1e.

6. Pressure diagrams obtained by each method are compared in Figure B1f. Uplift and total flow and exit gradients determined by the three methods are compared in Tables B1a and B1b, respectively.

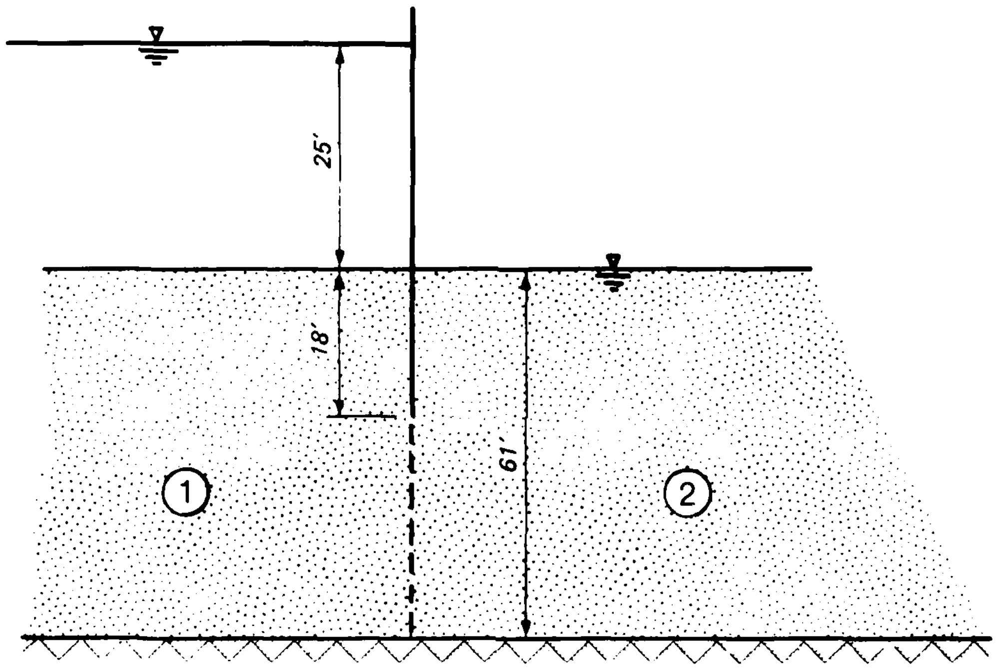


Figure B1a. Single sheetpile modeled by two fragments

```
CONFINED FLOW - METHOD OF FRAGMENTS
TIME  16 35:28                          DATE:  8/ 8/83

TITLE - Single Sheetpile
Q =  244 8471 (FT**2/DAY)
K =   14 4000 (FT/DAY)
Q/K =   17 00 (FT)
TOTAL HEAD LOSS =    25 00 (FT)
```

FRAG NO	FRAG TYPE	L (FT)	A (FT)	B (FT)	T (FT)	S1 (FT)	S2 (FT)	FORM FACTOR	HEAD LOSS (FT)
1	2				61 00	18.00		0.74	12 50
2	2				61 00	18.00		0.74	12 50

```
EXIT GRADIENT =  0.4338
```

RESULTANT FORCES ON STRUCTURE

LATERAL FORCE HEADWATER SIDE (LBS)	UPLIFT FORCE (LBS)	LATERAL FORCE TAILWATER SIDE (LBS)
50668 8	0.	17128.8

```
DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO
*N
```

Figure B1b. Program output for Example B1, method of fragments

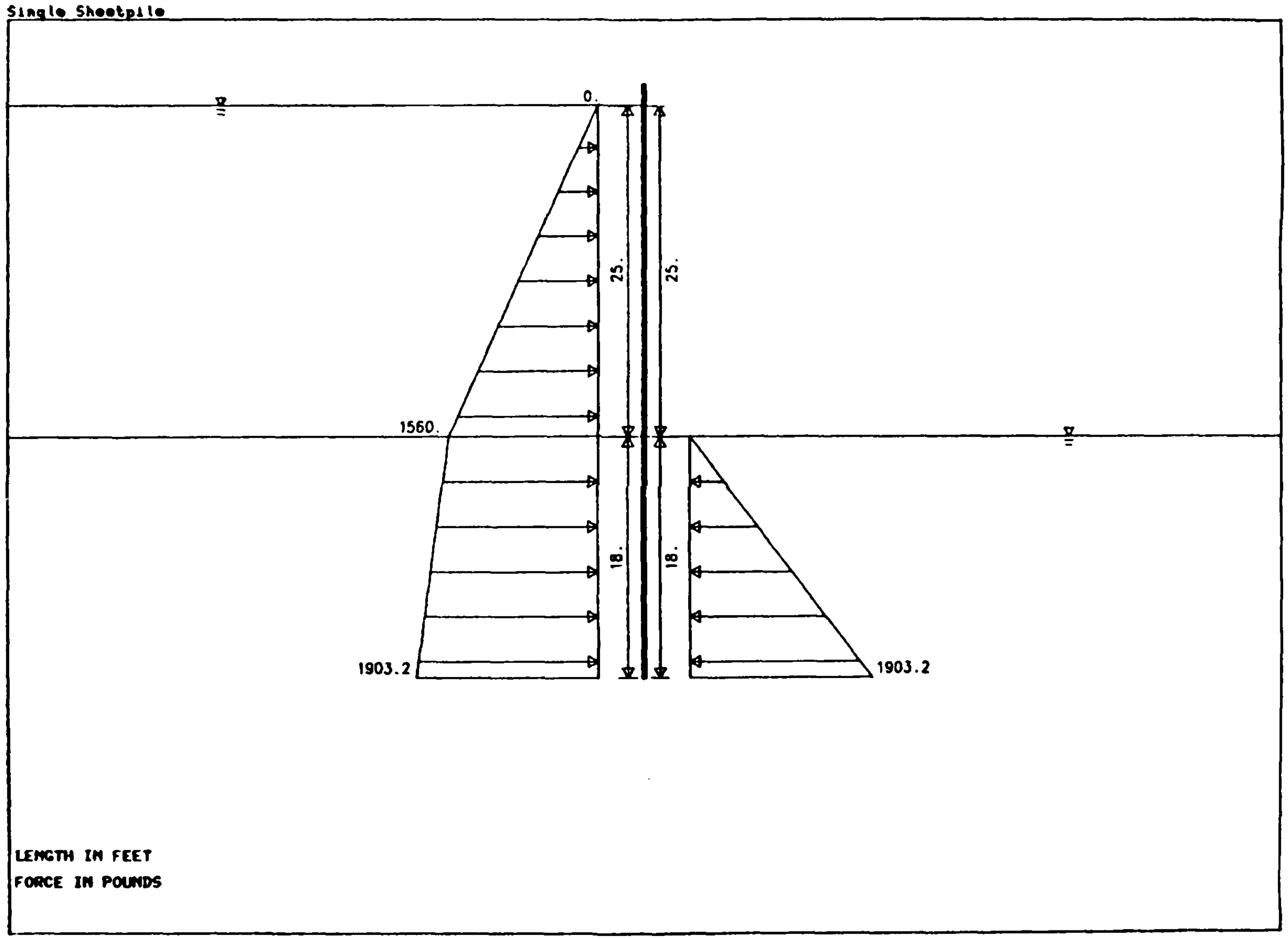


Figure B1c. Plot of pressures for Example B1, method of fragments

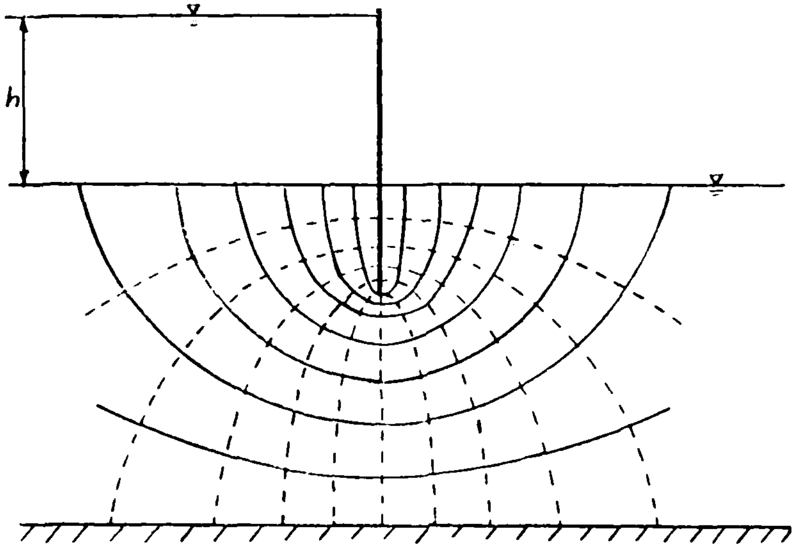


Figure B1d. Flownet analysis of single sheetpile

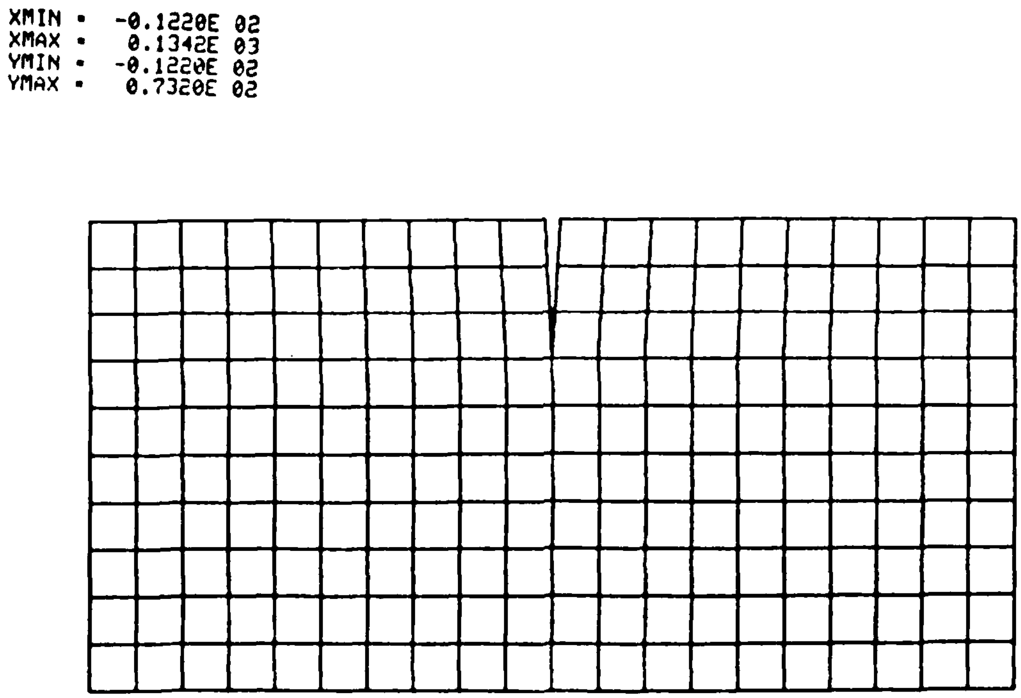


Figure B1e. Grid for finite element of single sheetpile

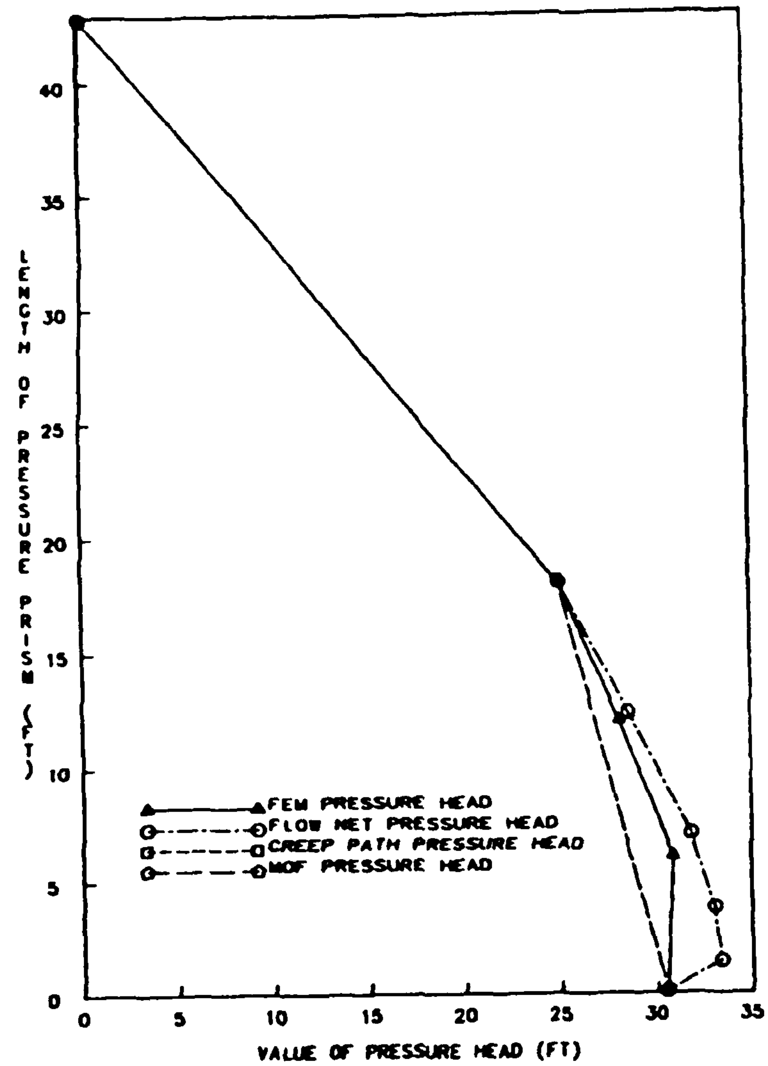


Figure B1f. Plot of pressure prism obtained by each method, Example B1

Table B1a

Uplift Comparison, Single Sheetpile

Method	Lateral Force on Headwater Side lb	Location of Resultant from Top ft	% Difference from Finite Element: Lateral Force	% Difference from Finite Element: Resultant Location
MOF	50668.8	27.512	2.55	0.670
CREEP	50668.8	27.512	2.55	0.670
FLOWNET	53272.0	27.924	2.46	0.816
FEM	51979.2	27.697		

Table B1b

Total Flow and Exit Gradient Comparison, Single Sheetpile

Method	Total Flow ft^3/day	Exit Gradient	% Difference from Finite Element: Flow	% Difference from Finite Element: Exit Gradient
MOF	244.8	0.4338	9.16	11.29
FLOWNET	240.0	0.37	11.14	27.04
FEM	268.3	0.4857		

Example B2: Dam with Sheetpile at Toe

7. The problem illustrated in Figure B2 is a typical example requiring sound engineering judgment to properly model a flow region.

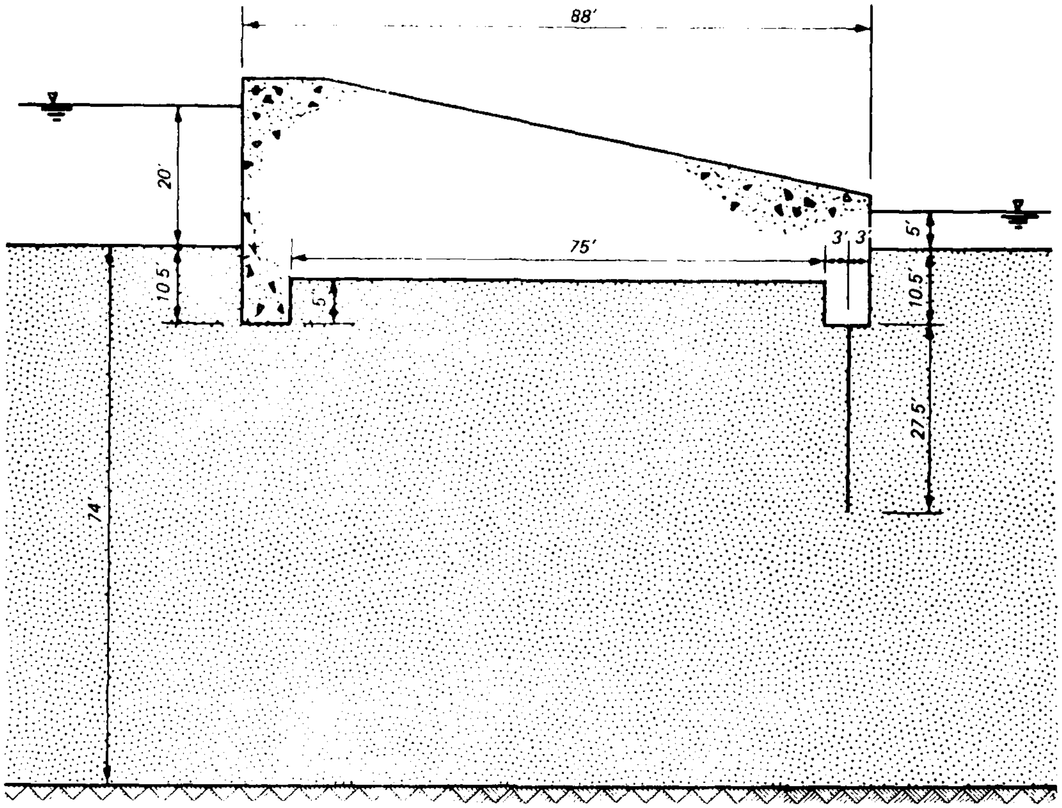


Figure B2. Dam with sheetpile at toe

8. The problem was divided into three fragments (Figure B2a) by assuming that the upstream and downstream keys have negligible thicknesses. These simplifications were necessary in order to obtain rational results. From an earlier discussion it was determined that the basic assumption in the development of the method of fragments was that the equipotential lines must be approximated by vertical lines. Had the geometry of the structure not been simplified, a flow region with six fragments (Figure B2b) would have resulted. Notice that these equipotential lines do not approximate the actual equipotential lines shown in Figure B2a. Consequently, results using this division would be incorrect.

9. The results of the program run are shown in Figures B2c and B2d, and the flownet for this problem is shown in Figure B2e. The grid used in

the finite element analysis is shown in Figure B2f. The plot of the pressure prism obtained by each method is shown in Figure B2g. Results obtained using each method are compared in Tables B2a and B2b.

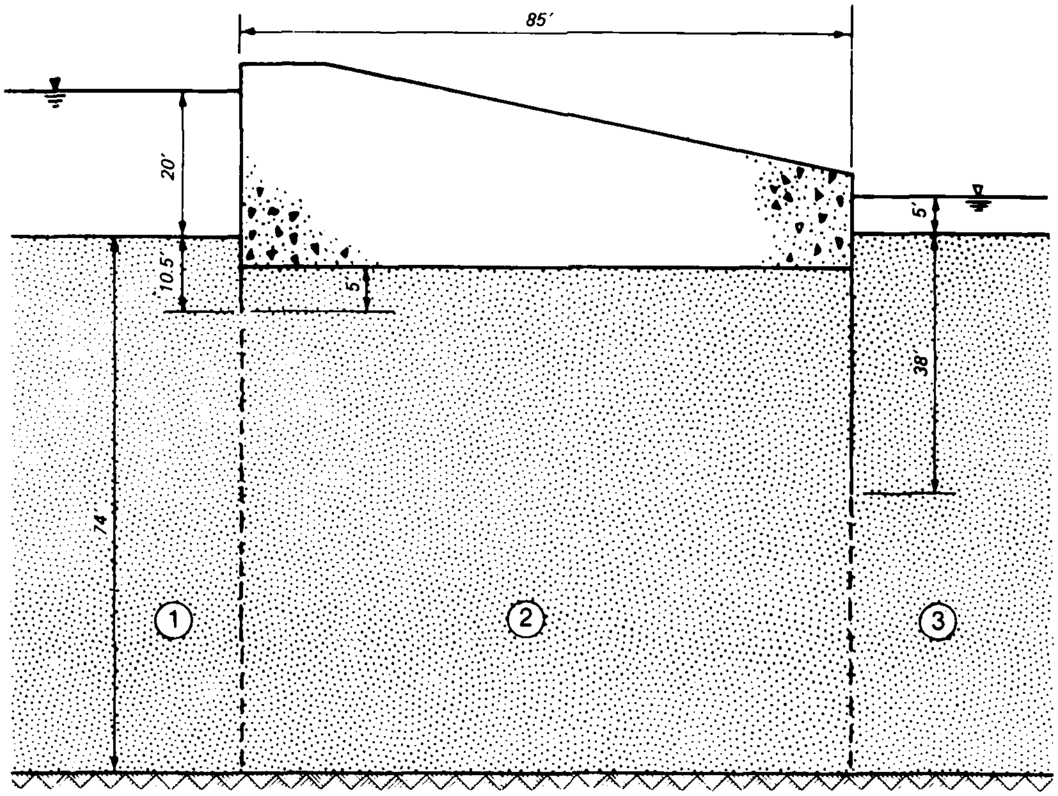


Figure B2a. Modeling of dam by using three fragments

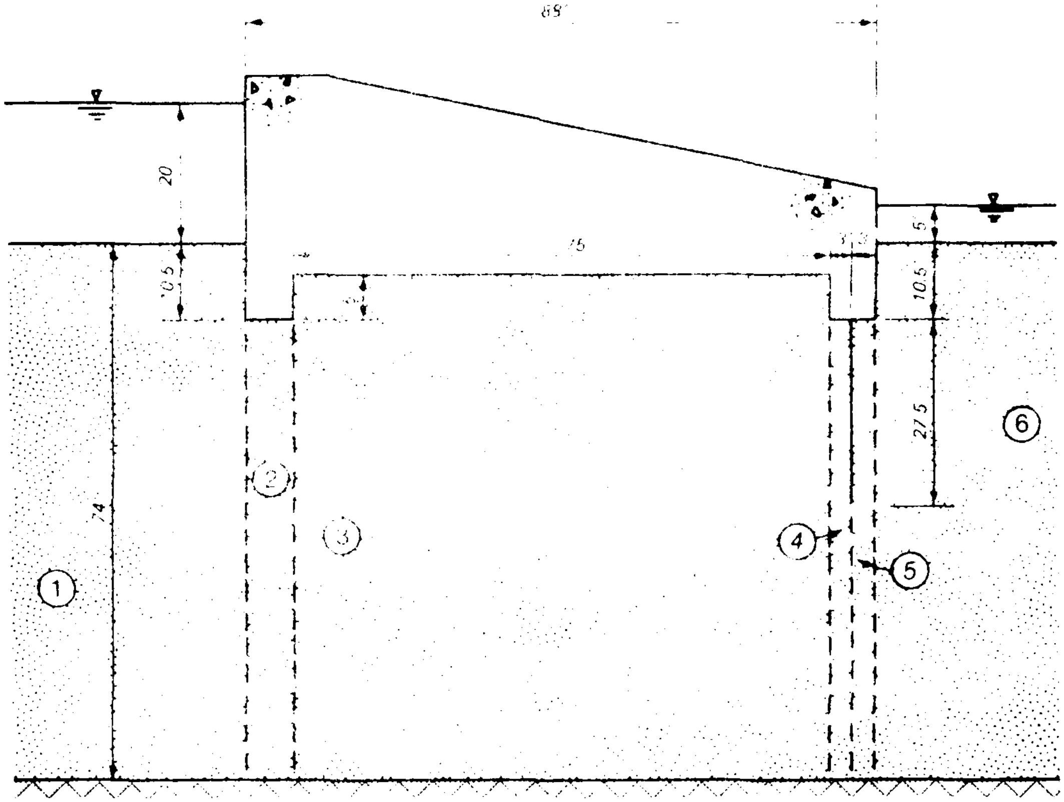


Figure [illegible]. Improper division of flow region

CONFINED FLOW - METHOD OF FRAGMENTS

TIME 16 53 46 DATE 8/ 8/83

TITLE - Dam with Sheetpile at Toe

Q = 72 5578 (FT**2/DAY)

K = 14 4000 (FT/DAY)

Q/K = 5 04 (FT)

TOTAL HEAD LOSS = 15 00 (FT)

FRAG NO	FRAG TYPE	L (FT)	A (FT)	B (FT)	T (FT)	S1 (FT)	S2 (FT)	FORM FACTOR	HEAD LOSS (FT)
1	2				74 00	10 50		0 54	2 75
2	6	55 00			62 50	5 00	32 50	1 41	7 12
3	2				74 00	39 00		1 02	5 14

EXIT GRADIENT = 0 08[illegible]

RESULTANT FORCES ON STRUCTURE

LATERAL FORCE HEADWATER SIDE (LBS)	UPLIFT FORCE (LBS)	LATERAL FORCE TAILWATER SIDE (LBS)
28124 5	106053 8	63779 8

DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO
=Y

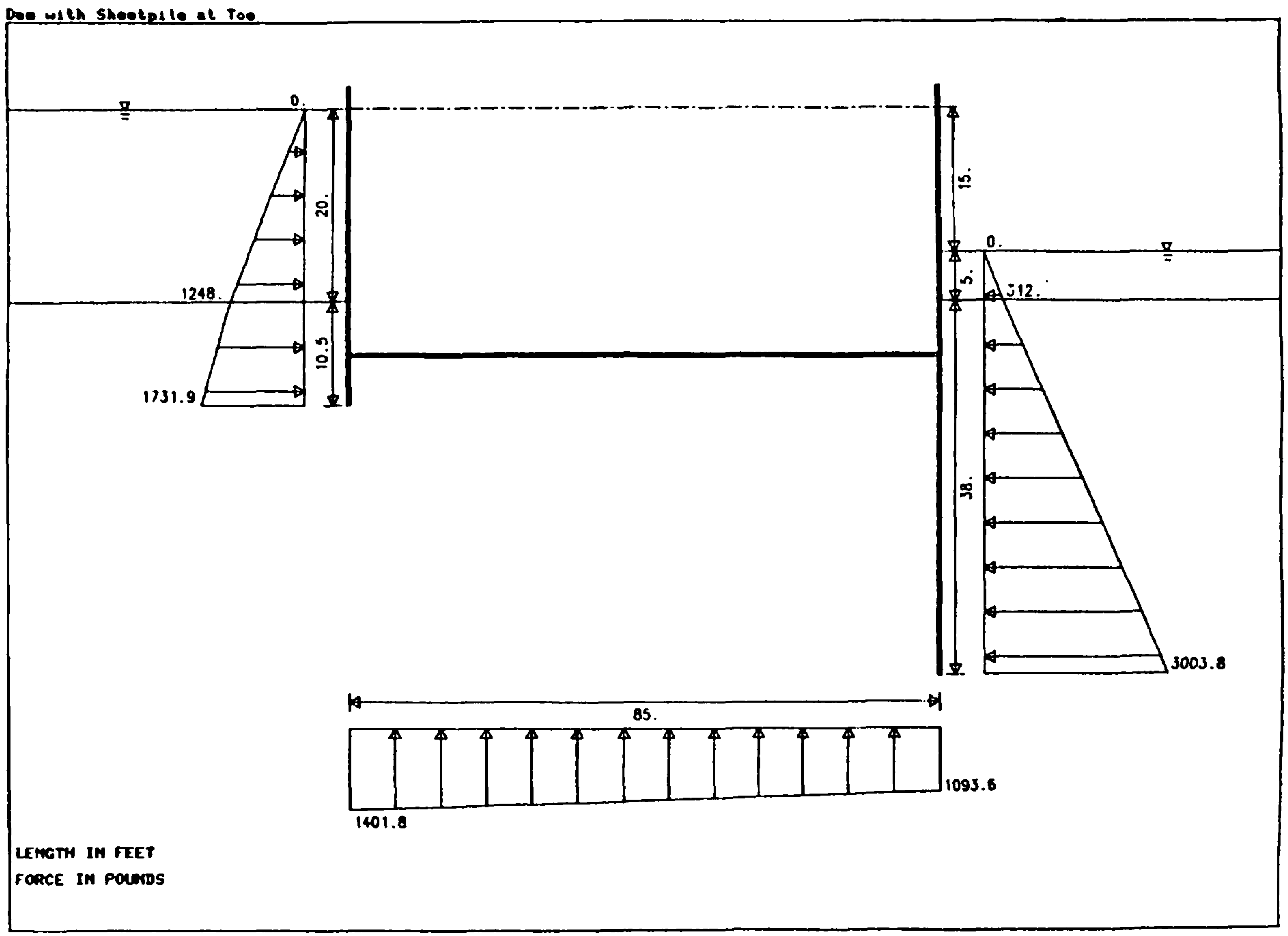


Figure B2d. Plot of pressures for Example B2: dam with sheetpile at toe

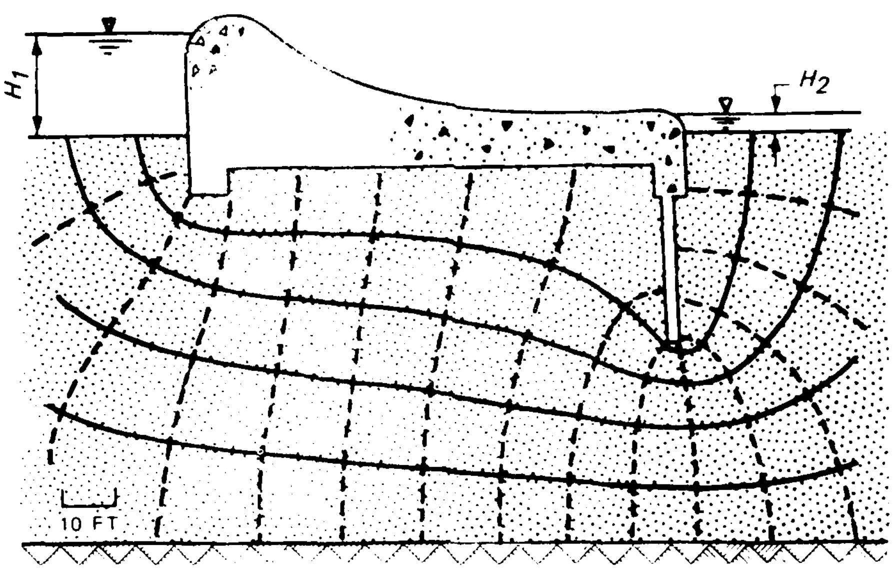


Figure B2e. Flownet analysis of Example B2: dam with sheetpile at toe

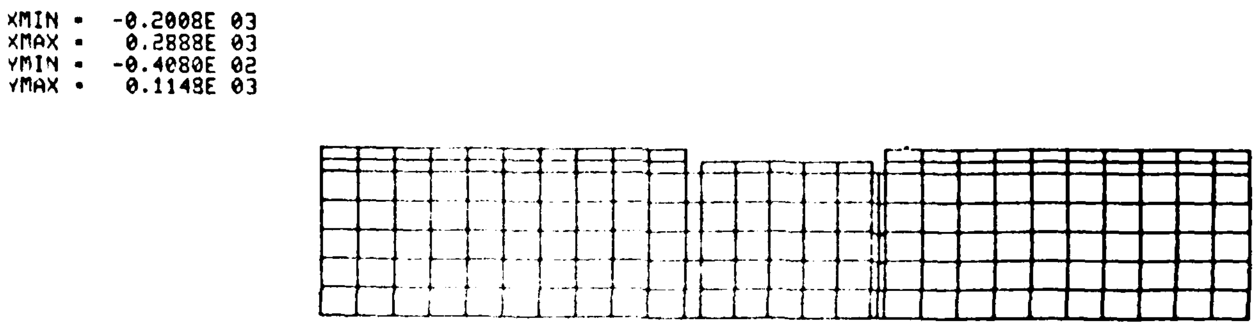


Figure B2f. Grid used for finite element analysis of Example B2

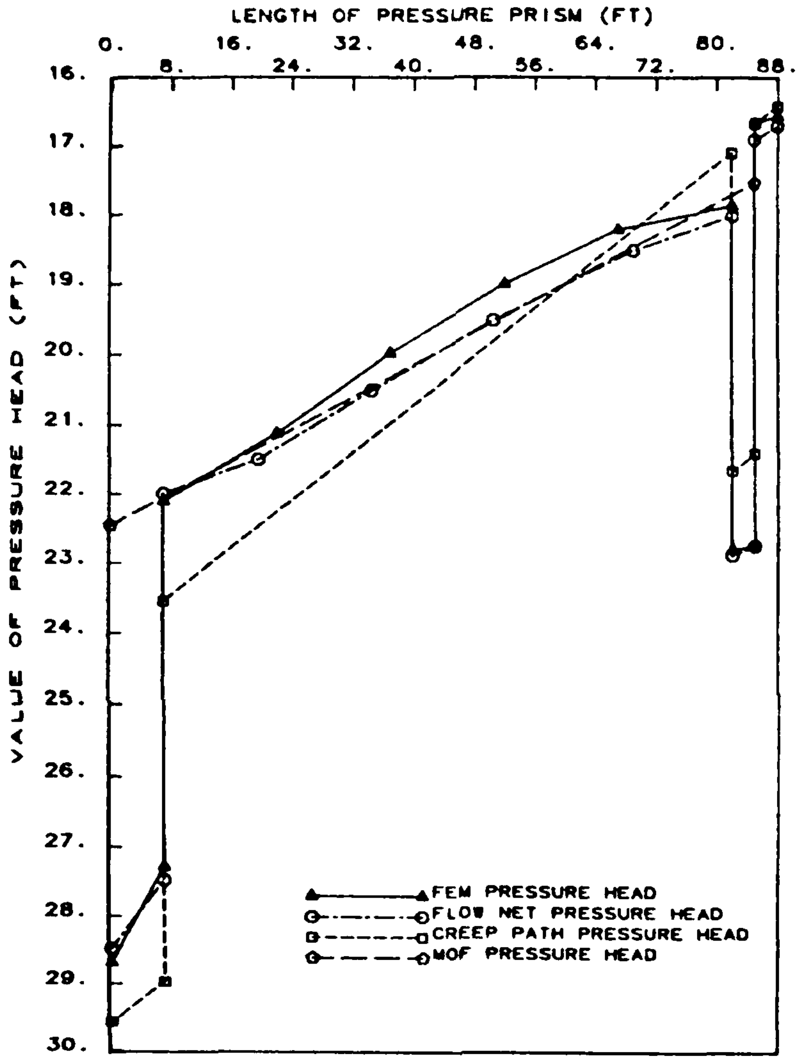


Figure B2g. Plot of pressure prisms obtained by each method, Example B2

Table B2a

Uplift Comparison, Dam with Sheetpile at Toe

Method	Total Uplift Force, lb	Location of Resultant from Left, ft	% Difference from Finite Element	
			Uplift Force	Resultant Location
MOF	106053.8	40.754	5.07	1.73
CREEP	115041.6	40.791	3.07	1.64
FLOWNET	112973.3	41.589	1.25	0.294
FEM	111568.7	41.467		

Table B2b

Total Flow and Exit Gradient Comparison, Dam with Sheetpile at Toe

Method	Total Flow ft^3/day	Exit Gradient	% Difference from Finite Element	
			Flow	Exit Gradient
MOF	72.6	0.0807	0.552	16.70
FLOWNET	72.0	0.1	0.277	4.71
FEM	72.2	0.0954		

10. Example B2 was reworked with the flow reversed. In essence, this places the sheetpile at the heel of the dam instead of at the toe. The program output is shown in Figures B2h and B2i. The flownet shown in Figure B2j is merely the reverse of that shown in Figure B2f. The finite element grid is also the same as shown in B2e. A plot of the pressure prism for each method is presented in Figure B2k. The methods are compared in Tables B2c and B2d.

```
CONFINED FLOW - METHOD OF FRAGMENTS
TIME  17  3:39                        DATE  8/ 8/83

TITLE - Dam with Sheetpile at Heel
Q =   72 5578 (FT**2/DAY)
K =   14 4000 (FT/DAY)
Q/K =    5 04 (FT)
TOTAL HEAD LOSS =   15 00 (FT)

FRAG FRAG                                                        FORM    HEAD
NO   TYPE     L        A        B        T        S1       S2    FACTOR  LOSS
             (FT)     (FT)     (FT)     (FT)     (FT)     (FT)           (FT)
-------------------------------------------------------------------------------
 1    2                                74 00    38 00             1 02    5 14
 2    6     85 00                      68 50    32 50    5.00     1 41    7.12
 3    2                                74 00    10 50             0 54    2 75

EXIT GRADIENT =  0 1657


                    RESULTANT FORCES ON STRUCTURE

          LATERAL FORCE     UPLIFT FORCE     LATERAL FORCE
          HEADWATER SIDE                     TAILWATER SIDE
              (LBS)             (LBS)            (LBS)

             98865 8          84890 2           8395.1

DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO
=Y
```

Figure B2h. Program output for Example B2, dam with sheetpile at heel

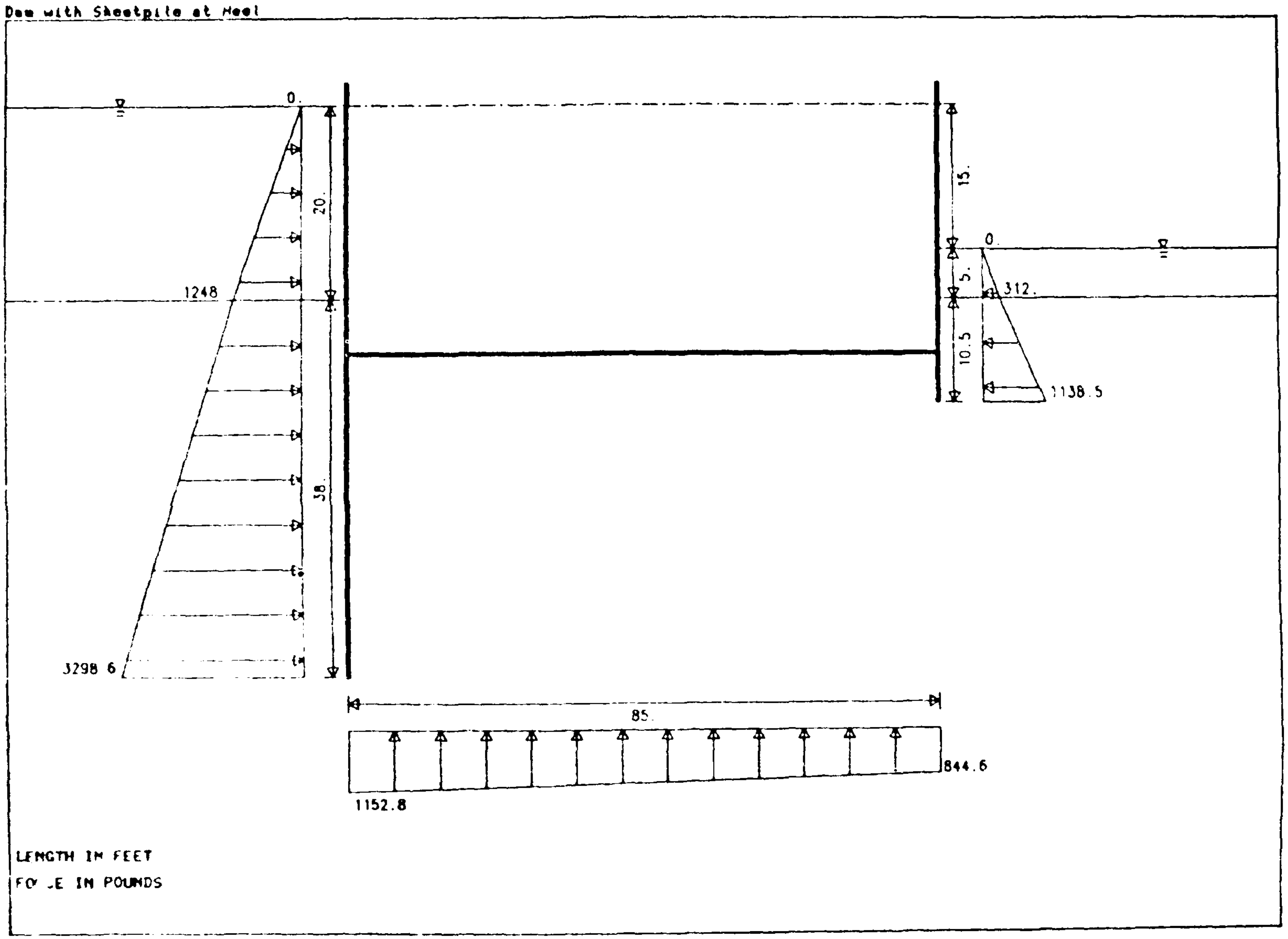


Figure B2i. Plot of pressures for Example B2: dam with sheetpile at heel

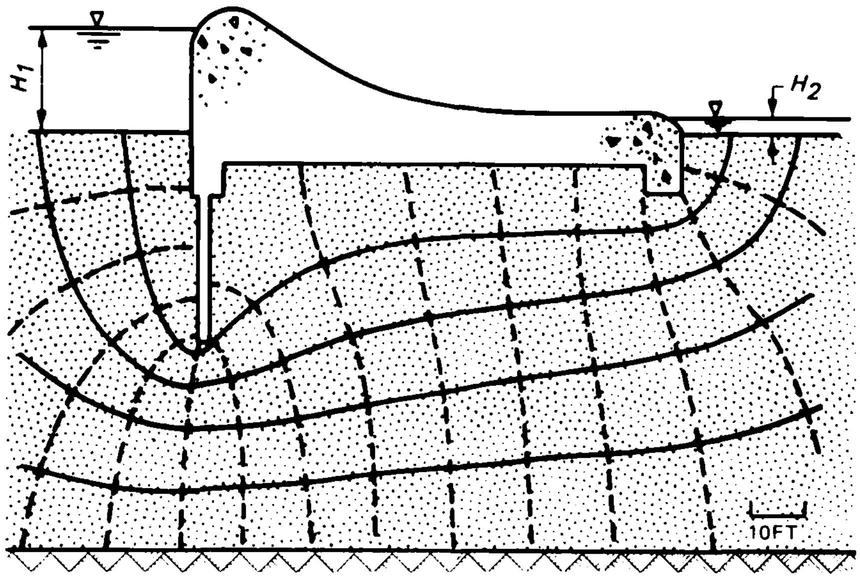


Figure B2j. Flownet of Example B2, dam with sheetpile at heel

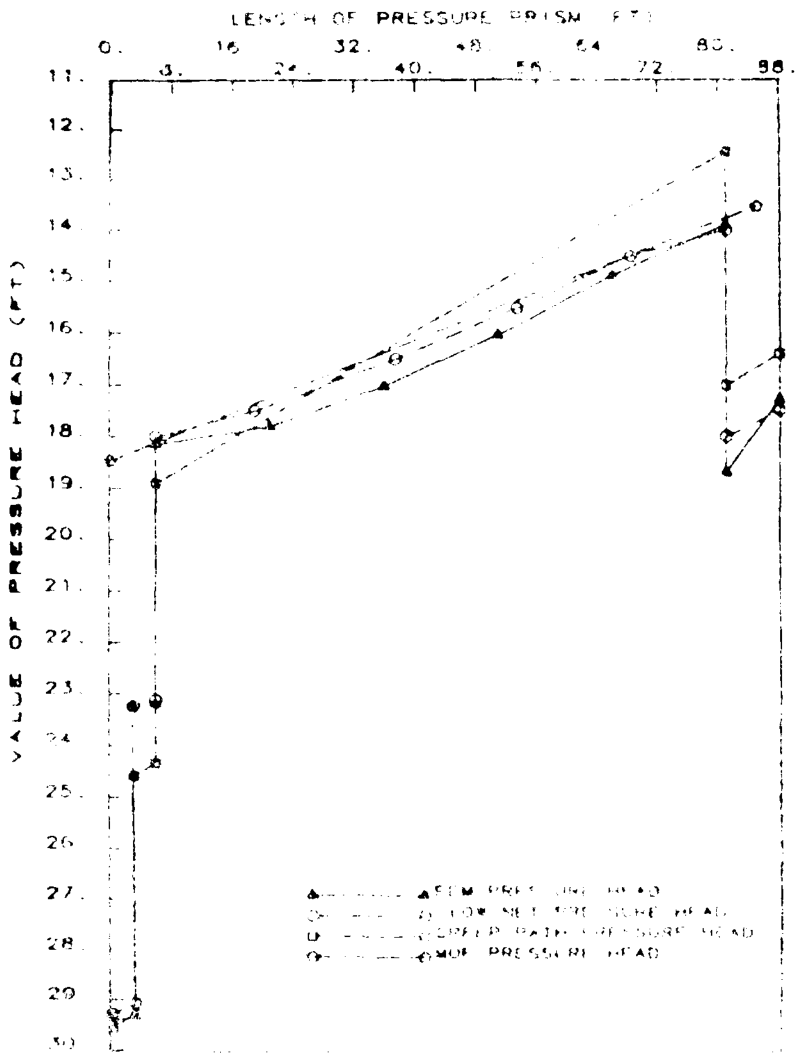

LENGTH OF PRESSURE PRISM (FT)
0. 16 32. 48 64 80.
8. 24. 40. 56 72 88.
11. 12. 13. 14 15. 16. 17. 18. 19. 20. 21. 22. 23. 24 25. 26 27. 28. 29 30
VALUE OF PRESSURE HEAD (FT)

Table B2c

Uplift Comparison, Dam with Sheetpile at Heel

Method	Total Uplift Force, lb	Location of Resultant from Left, ft	% Difference from Finite Element	
			Uplift Force	Resultant Location
MOF	84864.0	40.313	10.46	2.30
CREEP	90753.6	40.189	3.75	2.60
FLOW NET	92712.7	41.268	1.62	0.0461
FEM	94226.5	41.249		

Table B2d

Total Flow and Exit Gradient Comparison, Dam with Sheetpile at Heel

Method	Total Flow ft^3/day	Exit Gradient	% Difference from Finite Element	
			Flow	Exit Gradient
MOF	72.6	0.1657	0.552	7.13
FLOW NET	72.0	0.15	0.277	2.83
FEM	72.2	0.1543		

APPENDIX C: PARAMETRIC STUDY

1. A brief parametric study was performed to compare the method of fragments with the method of creep. The accuracy of each method was evaluated using the finite element method with the grid shown in Figure C1. In the analysis, location, length, and number of sheetpiles were varied while the width and depth of the flow region were held constant.

2. The total uplift pressure, the location of the resultant uplift, the total flow, and the exit gradient were compared. Also, a plot of the uplift pressure diagrams is included.

3. The results show that the assumption of vertical equipotential lines between fragments made in the method of fragments is more accurate when the length of the sheetpiles increases and/or when two sheetpiles are present under the structure. Corresponding to a decrease in the difference between the actual and assumed equipotential lines was an increase in the accuracy of the method of fragments solutions.

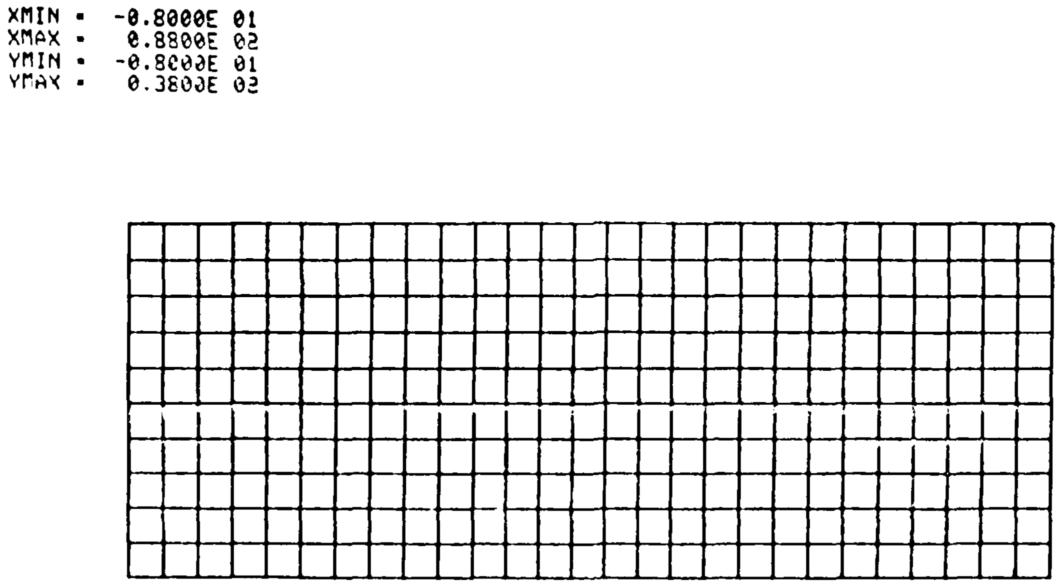
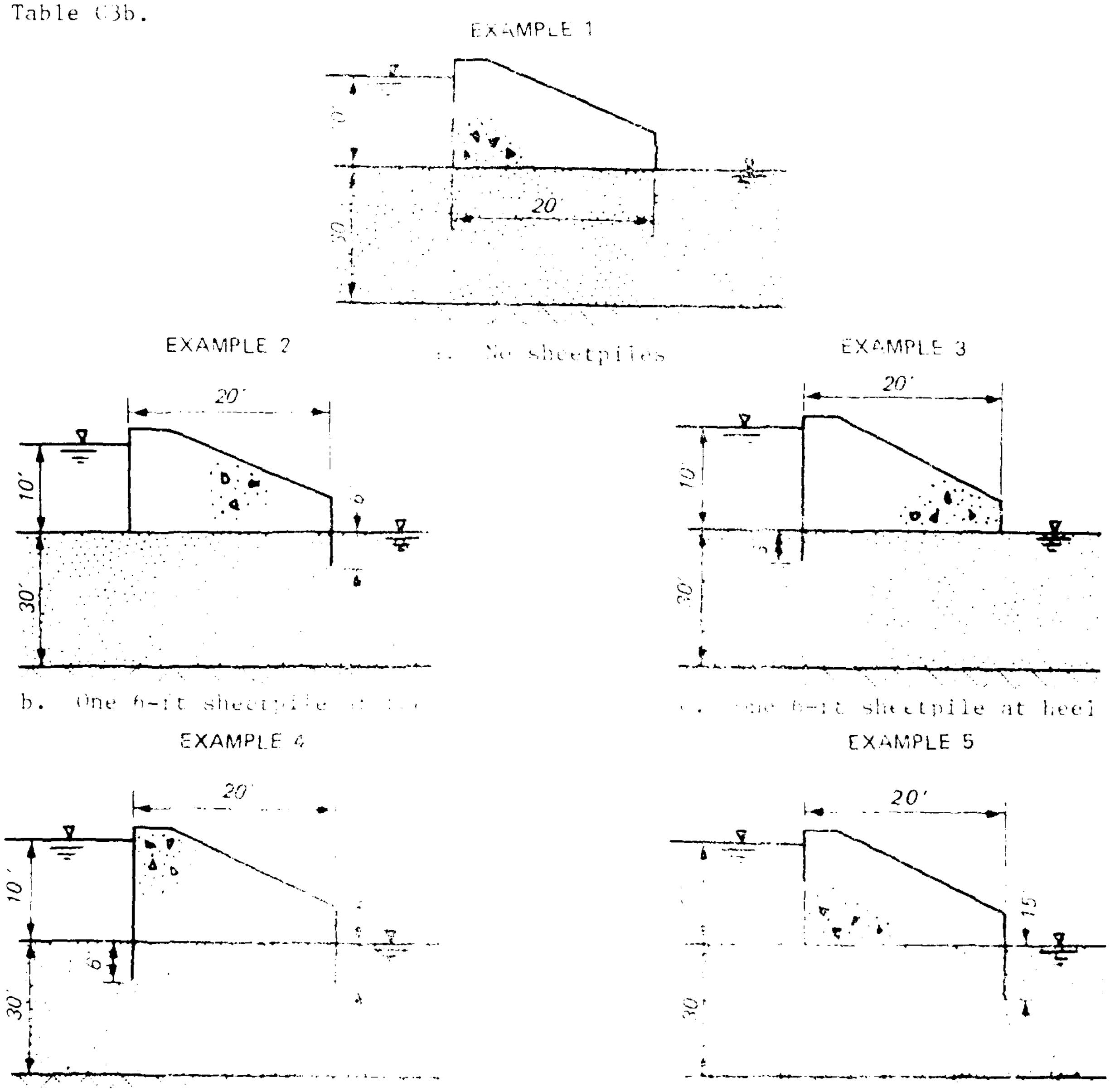


Figure C1. Grid used in finite element analysis of the various dams in the parametric study

[illegible], Dam with No Sheetpiles

4. As shown in Figure [illegible], Example 1 is a dam with no sheetpiles. The method of fragments [illegible] is shown in Figures [illegible] and C3b. A plot of the uplift pressures [illegible] is shown in Figure [illegible]. The uplift comparison is shown in [illegible] flow and [illegible] are compared in Table C3b.



a. No sheetpiles

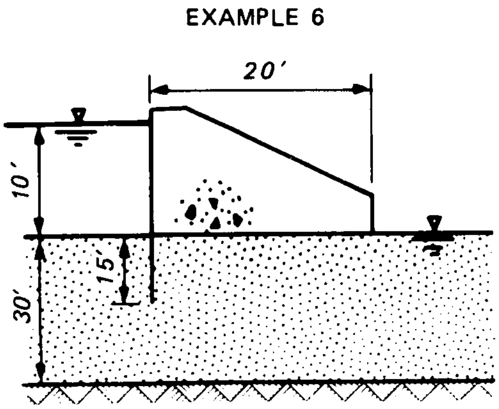
b. One 6-ft sheetpile [illegible]

c. One 6-ft sheetpile at heel

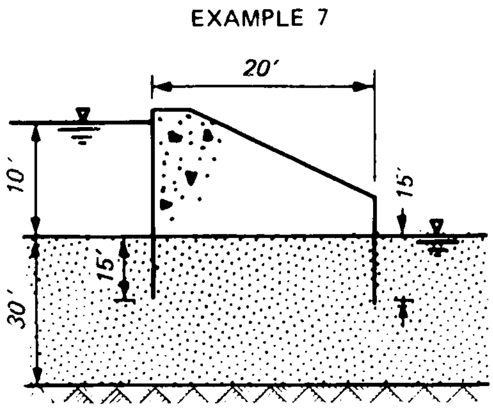
d. Two 6-ft [illegible]

[illegible] sheetpile at toe

Figure [illegible]



f. One 15-ft sheetpile at heel



g. Two 15-ft sheetpiles

Figure C2. (Concluded)

```
CONFINED FLOW - METHOD OF FRAGMENTS
TIME  17  7 11                       DATE   8/ 8/83

TITLE - Dam with no Sheetpiles
Q =    94 2068 (FT**2/DAY)
K =    14 4000 (FT/DAY)
Q/K =      6 54 (FT)
TOTAL HEAD LOSS =    10 00 (FT)
```

FRAG NO	FRAG TYPE	L (FT)	A (FT)	B (FT)	T (FT)	S1 (FT)	S2 (FT)	FORM FACTOR	HEAD LOSS (FT)
1	3			10 00	30 00	0		0 76	5 00
2	3			10 00	30 00	0		0 76	5 00

WARNING - THERE IS NO EMBEDMENT ON THE TAILWATER SIDE.
EXIT GRADIENT IS INFINITE AND PIPING MAY OCCUR

RESULTANT FORCES ON STRUCTURE

LATERAL FORCE HEADWATER SIDE (LBS)	UPLIFT FORCE (LBS)	LATERAL FORCE TAILWATER SIDE (LBS)
3120 0	6240 0	0

DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO.
=Y

Figure C3a. Program output for Example 1

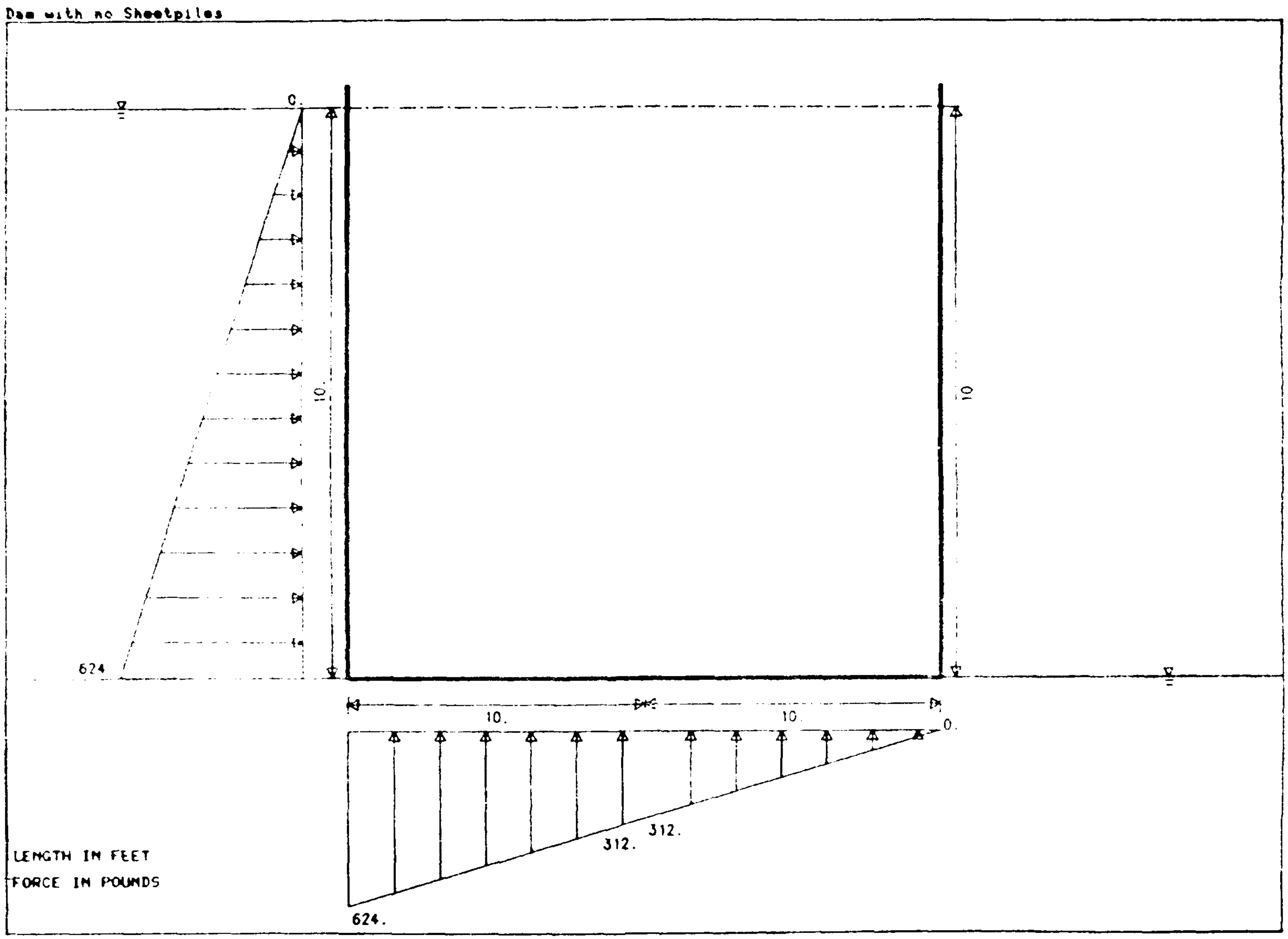


Figure C3b. Plot of pressures for Example 1

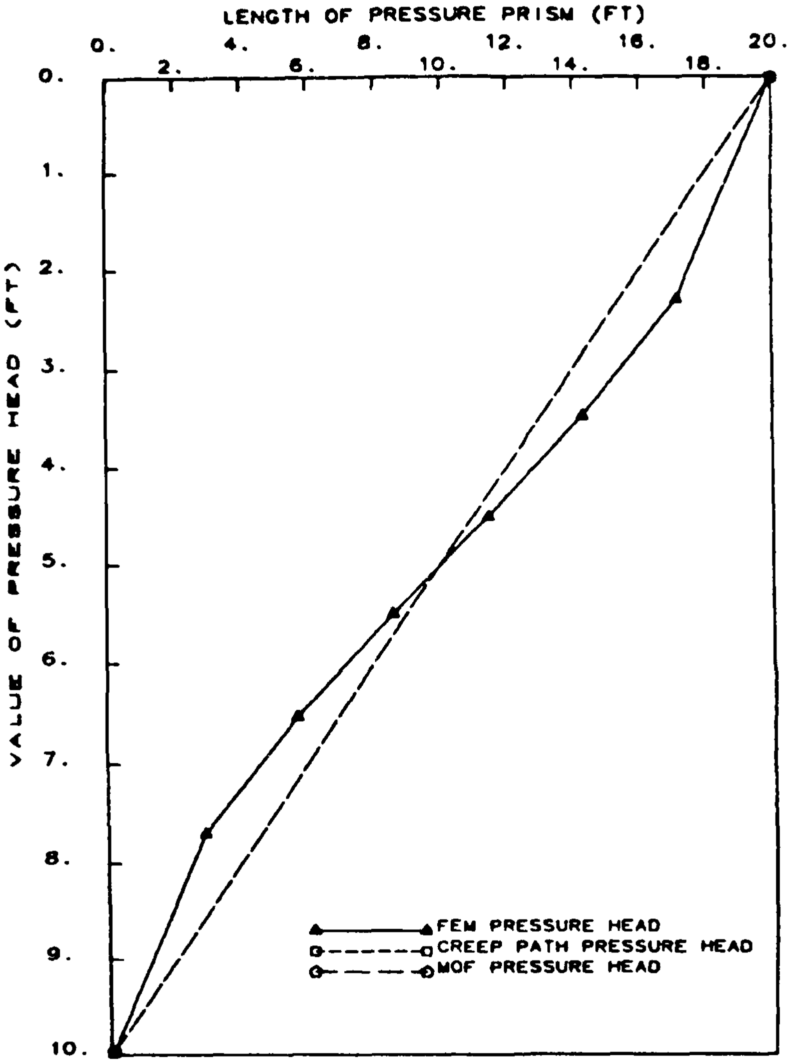


Figure C3c. Plot of uplift pressures for each method for Example 1

Table C3a

Uplift Comparison for Example 1, Dam With No Sheetpiles

Method	Total Uplift Force, lbs	Location of Resultant from Left ft	% Difference from Finite Element	
			Uplift Force	Resultant Location
MOF	6240.0	6.667	0.029	7.49
CREEP	6240.0	6.667	0.029	7.49
FEM	6241.8	7.186		

Table C3b

Total Flow and Exit Gradient Comparison For Example 1,

Dam With No Sheetpiles

Method	Total Flow (ft^3/day)	Exit Gradient	% Difference from Finite Element	
			Flow	Exit Gradient
MOF	94.2	*	5.97	*
FEM	100	*		

* Exit gradient is infinite for case of no embedment on downstream side.

Example 2, One 6-ft Sheetpile at Toe

5. As shown in Figure C2b, Example 2 is a dam with one 6-ft sheetpile at toe. The method of fragments solution is shown in Figures C4a and C4b. A plot of the uplift pressures for each method is shown in Figure C4c. The uplift comparison for Example 2 is shown in Table C4a, and the total flow and exit gradient are compared in Table C4b.

```
     CONFINED FLOW - METHOD OF FRAGMENTS
     TIME  17:14:59                        DATE:  8/ 8/83

TITLE - Dam with one 6' Sheetpile
Q =    81 5057 (FT**2/DAY)
K =    14 4000 (FT/DAY)
Q/K =     5 66 (FT)
TOTAL HEAD LOSS =    10 00 (FT)
FRAG FRAG                                                           FORM      HEAD
NO   TYPE       L         A         B         T         S1        S2    FACTOR    LOSS
               (FT)      (FT)      (FT)      (FT)      (FT)      (FT)             (FT)
------------------------------------------------------------------------------------
 1    3                            20.00     30 00     6 00                1.15      6 49
 2    2                                      30 00     6.00                0.62      3.51
EXIT GRADIENT =   0 3689


                      RESULTANT FORCES ON STRUCTURE

            LATERAL FORCE      UPLIFT FORCE        LATERAL FORCE
            HEADWATER SIDE                         TAILWATER SIDE
               (LBS)              (LBS)               (LBS)

              5836 4             9363.0              1779 6

DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO
=Y
```

Figure C4a. Program output for Example 2

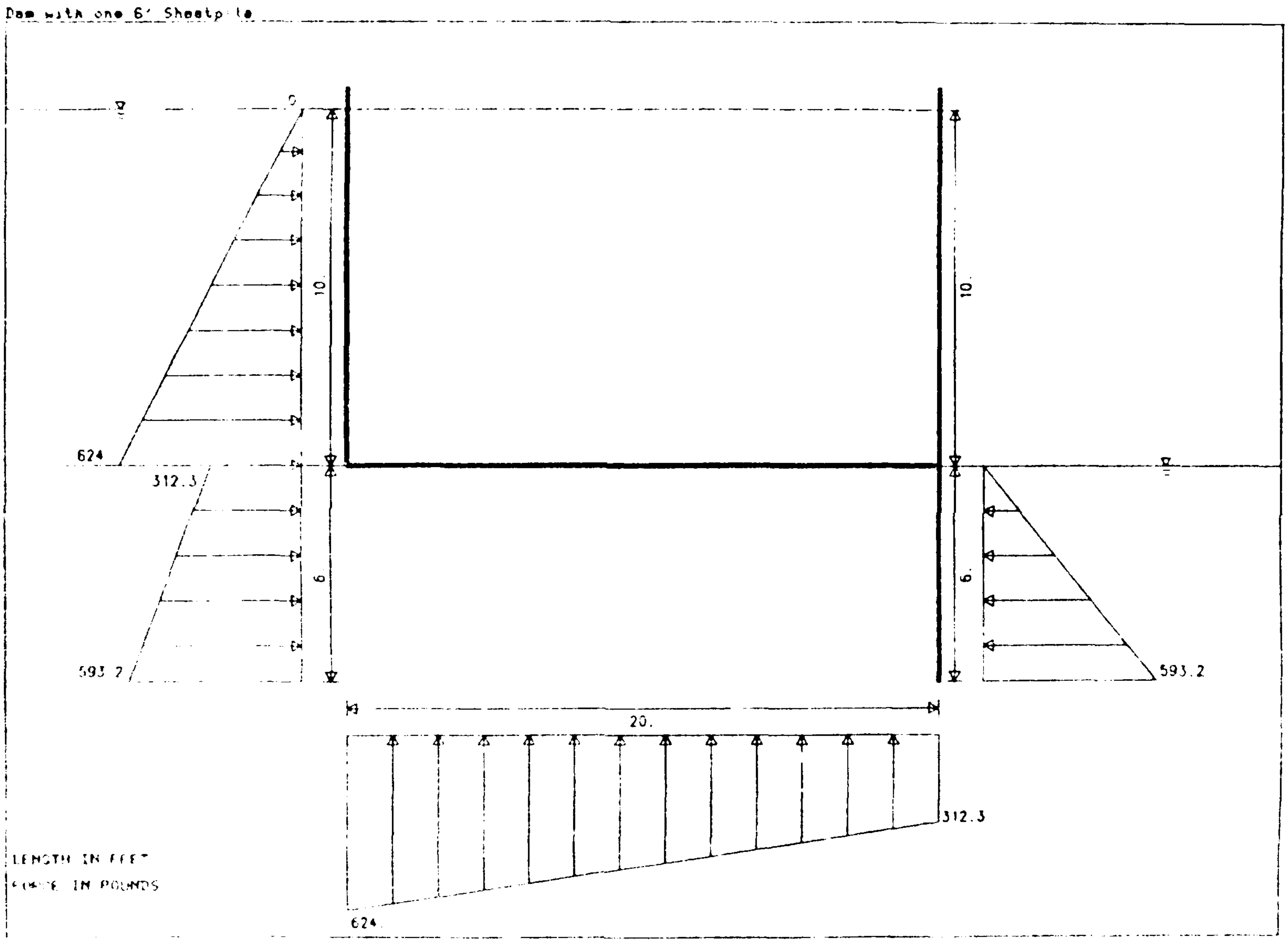


Figure No. [illegible]. Plot of Pressures for Example [illegible].

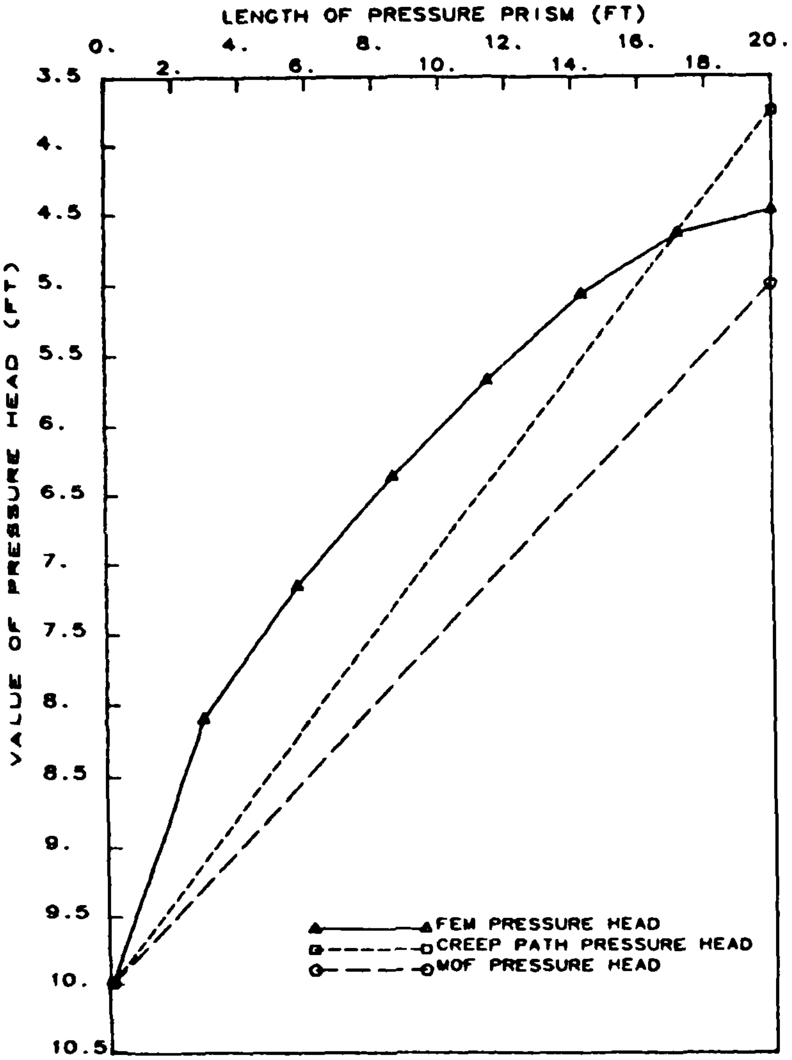


Figure C4c. Plot of uplift pressure for each method for Example 2

Table C4a

Uplift Comparison for Example 2, Dam With

One 6-ft Sheetpile at Toe

Method	Total Uplift Force, lbs	Location of Resultant from Left, ft	% Difference from Finite Element	
			Uplift Force	Resultant Location
MOF	9360.0	8.889	17.04	2.71
CREEP	8580.0	8.485	8.36	1.94
FEM	7896.0	8.651		

Table C4b

Total Flow and Exit Gradient Comparison for Example 2,

Dam With One 6-ft Sheetpile at Toe

Method	Total Flow ft^3/day	Exit Gradient	% Difference from Finite Element	
			Flow	Exit Gradient
MOF	81.5	0.3689	5.84	2.16
FEM	86.4	0.3610		

Example 3, Dam With One 6-ft Sheetpile at Heel

6. As shown in Figure C2c, Example 3 is a dam with one 6-ft sheetpile at heel. The method of fragments solution is shown in Figures C5a and C5b. A plot of the uplift pressures for each method is shown in Figure C5c. The uplift comparison is shown in Table C5a. The total flow and exit gradient are compared in Table C5b.

```
CONFINED FLOW - METHOD OF FRAGMENTS
TIME: 11:24: 7                                  DATE: 8/11/83

TITLE - Dam with one 6' Sheetpile
Q =   81.5057 (FT**2/DAY)
K =   14.4000 (FT/DAY)
Q/K =     5.66 (FT)
TOTAL HEAD LOSS =    10.00 (FT)

FRAG FRAG                                                      FORM    HEAD
NO.  TYPE    L       A       B       T       S1      S2      FACTOR  LOSS
            (FT)    (FT)    (FT)    (FT)    (FT)    (FT)             (FT)
------------------------------------------------------------------------------
 1    2                             30.00    6.00             0.62    3.51
 2    3                     20.00   30.00    6.00             1.15    6.49
WARNING - THERE IS NO EMBEDMENT ON THE TAILWATER SIDE.
EXIT GRADIENT IS INFINITE AND PIPING MAY OCCUR.

                    RESULTANT FORCES ON STRUCTURE
          LATERAL FORCE       UPLIFT FORCE       LATERAL FORCE
          HEADWATER SIDE                         TAILWATER SIDE
             (LBS)               (LBS)               (LBS)

            7330.8              3117.0              3274.0

DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO.
=Y
```

Figure C5a. Program output for Example 3

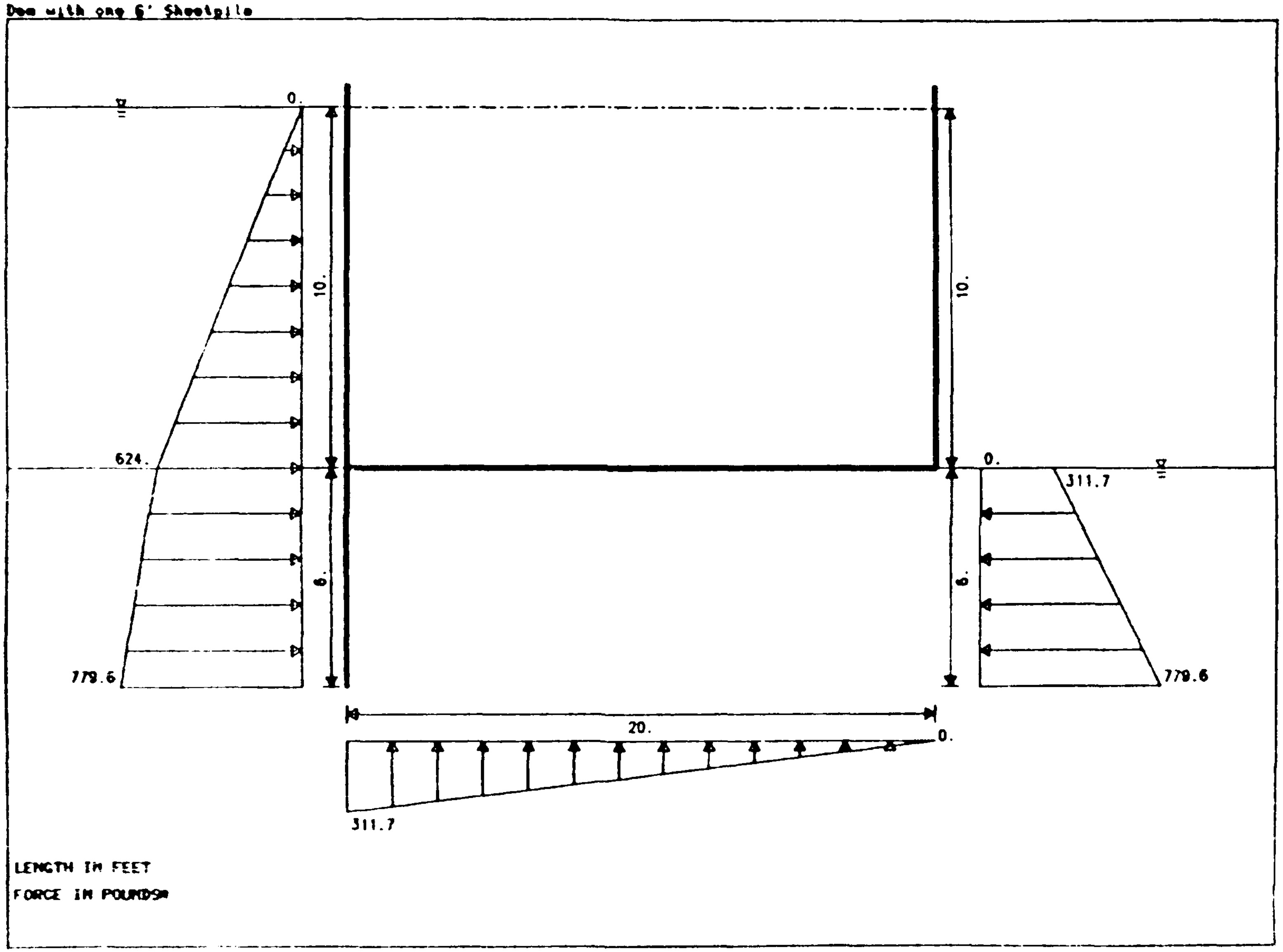


Figure C6b. Plot of pressures for Example 3

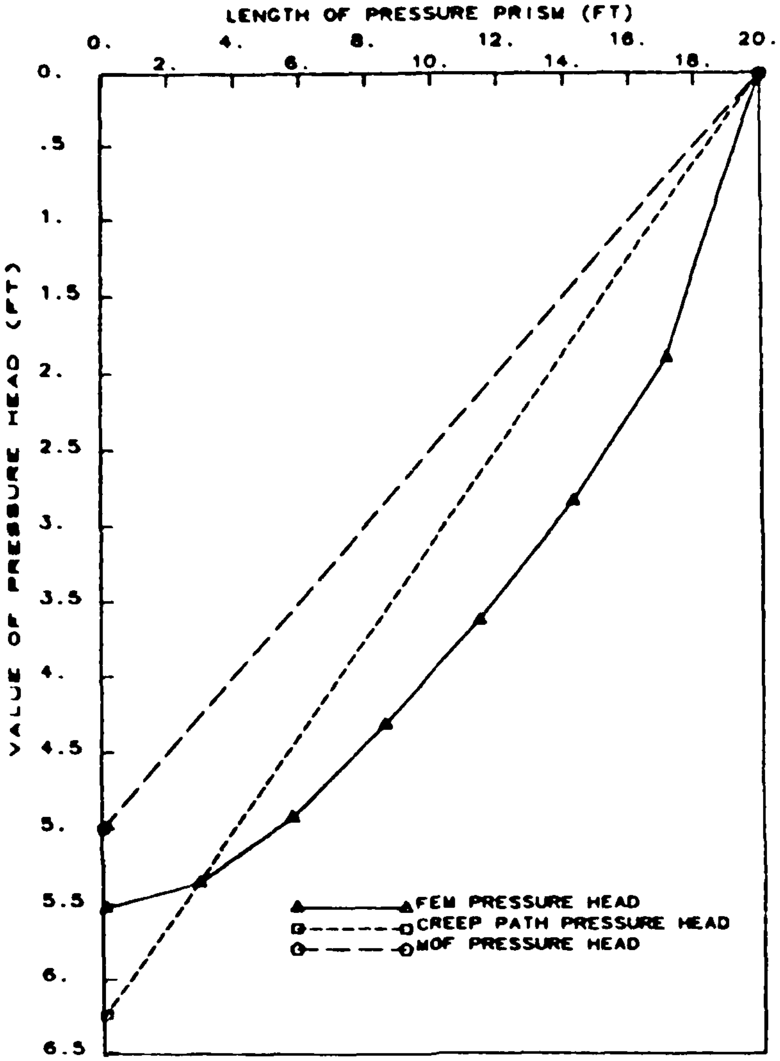


Figure C5c. Plot of uplift pressures for each method for Example 3

Example 4, Dam With Two 6-ft Sheetpiles

6. As shown in Figure C2d, Example 4 is a dam with two 6-ft sheetpiles. The method of fragments solution is shown in Figures C6a and C6b. A plot of the uplift pressures for each method is shown in Figure C6c. The uplift comparison is shown in Table C6a. The total flow and exit gradient are compared in Table C6b.

```
CONFINED FLOW - METHOD OF FRAGMENTS
TIME  17:10:35                          DATE:  8/ 8/83

TITLE - Dam with two 6' Sheetpiles
Q =   73.7761 (FT**2/DAY)
K =   14.4000 (FT/DAY)
Q/K =     5.12 (FT)
TOTAL HEAD LOSS =    10.00 (FT)
```

FRAG NO	FRAG TYPE	L (FT)	A (FT)	B (FT)	T (FT)	S1 (FT)	S2 (FT)	FORM FACTOR	HEAD LOSS (FT)
1	2				30.00	6.00		0.62	3.17
2	5	20.00			30.00	6.00		0.71	3.65
3	2				30.00	6.00		0.62	3.17

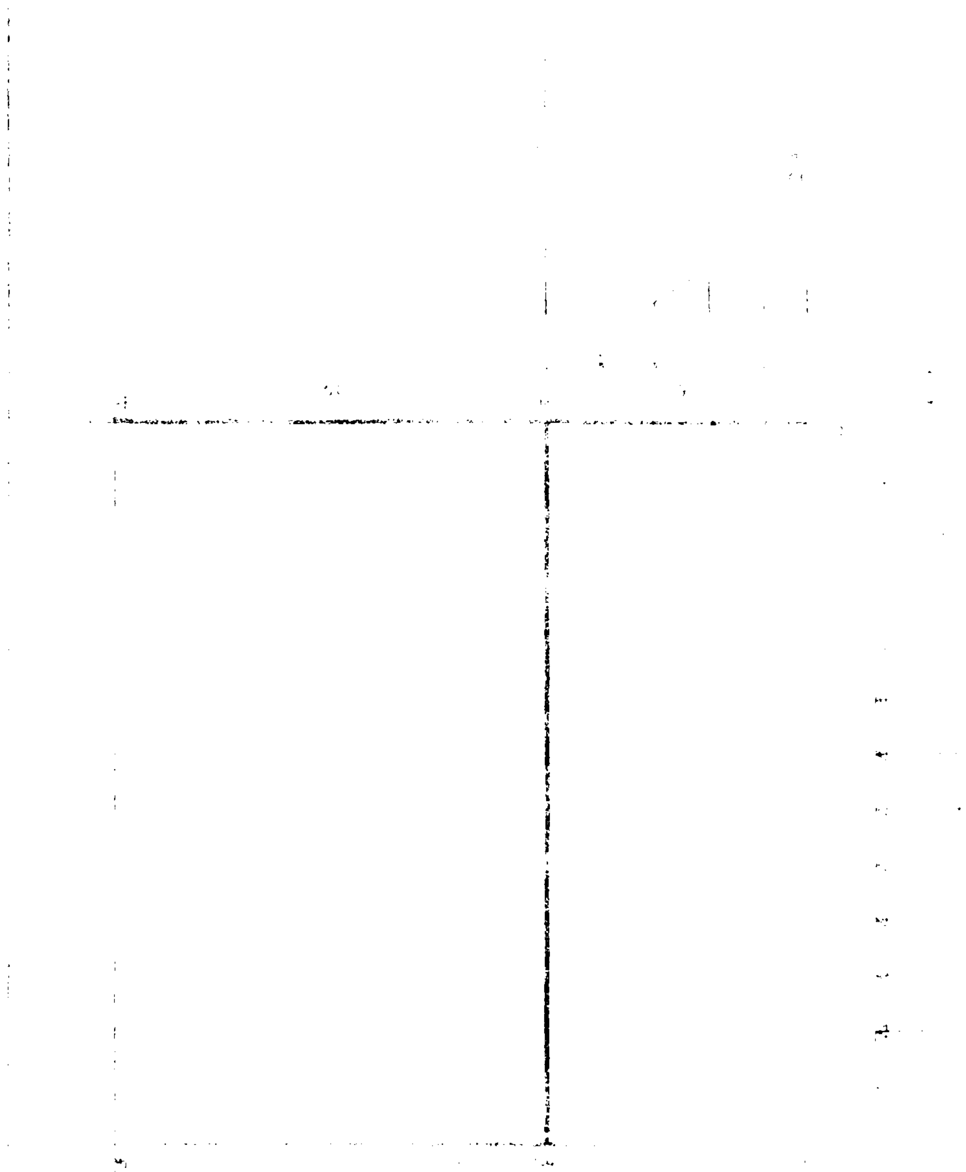
EXIT GRADIENT = 0.3339

RESULTANT FORCES ON STRUCTURE

LATERAL FORCE HEADWATER SIDE (LBS)	UPLIFT FORCE (LBS)	LATERAL FORCE TAILWATER SIDE (LBS)
7393.1	6240.0	1717.3

DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO
=Y

Figure C6a. Program output for Example 4



AD-A150 015 COMPUTER-AIDED STRUCTURAL ENGINEERING (CASE) PROJECT SEEPAGE ANALYSIS OF..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS M E PACE ET AL. SEP 84 2/2

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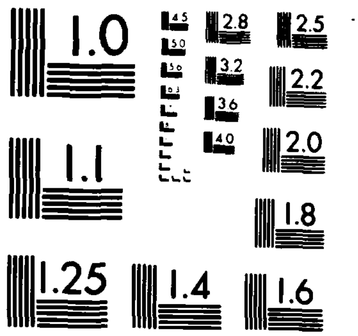

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

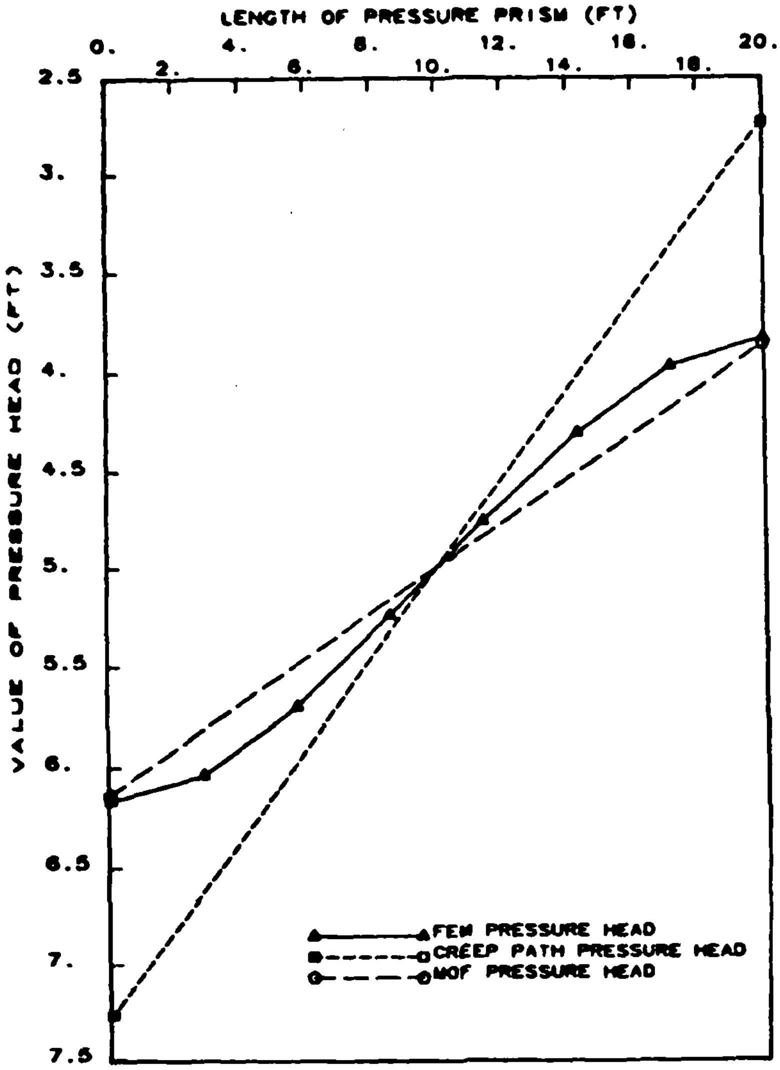

Figure C6c. Plot of uplift pressures for each method for Example 4

Table C6a

Uplift Comparison for Example 6, Dam with Two 6-ft Sheetpiles

Method	Total Uplift Force, lbs	Location of Resultant from Left, ft	% Difference from Finite Element Uplift Force	% Difference from Finite Element Location
MOF	6240.0	9.[illegible]40	[illegible]	[illegible]
CREEP	6240.0	8.487	.0[illegible]6	6.806
FEM	6[illegible]43.6	[illegible]85		

Table C6b

Total Flow and Exit Gradient Comparison for Example 6, Dam With Two 6-ft Sheetpiles

[illegible]	Total Flow ft^3/day	Exit Gradient	% Difference from Finite Element Flow	% Difference from Finite Element Exit Gradient
[illegible]	73.7	0.[illegible]69	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		

Example 5, Dam With One 15-ft Sheetpile at Toe

7. As shown in Figure C2e, Example 5 is a dam with one 15-ft sheetpile at the toe. The method of fragments solution is shown in Figures C7a and C7b. A plot of the uplift pressures for each method is shown in Figure C7c. The uplift comparison is shown in Table C7a. The total flow and exit gradient are compared in Table C7b.

```
    CONFINED FLOW - METHOD OF FRAGMENTS
    TIME  17:17:15                          DATE:  8/ 8/83

TITLE - Dam with one 15' Sheetpile
Q =    60.7944 (FT**2/DAY)
K =    14.4000 (FT/DAY)
Q/K =     4.22 (FT)
TOTAL HEAD LOSS =    10.00 (FT)
FRAG FRAG                                                        FORM     HEAD
NO   TYPE      L         A         B         T         S1        S2      FACTOR   LOSS
              (FT)      (FT)      (FT)      (FT)      (FT)      (FT)              (FT)
-----------------------------------------------------------------------------------------
 1    3                            20.00     30.00     15.00               1.37     5.78
 2    2                                      30.00     15.00               1.00     4.22
EXIT GRADIENT =  0.1686


                       RESULTANT FORCES ON STRUCTURE
              LATERAL FORCE      UPLIFT FORCE       LATERAL FORCE
              HEADWATER SIDE                        TAILWATER SIDE
                 (LBS)              (LBS)               (LBS)

                15250.6            10419.7             8995.8


DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO
=Y
```

Figure C7a. Program output for Fxample 5

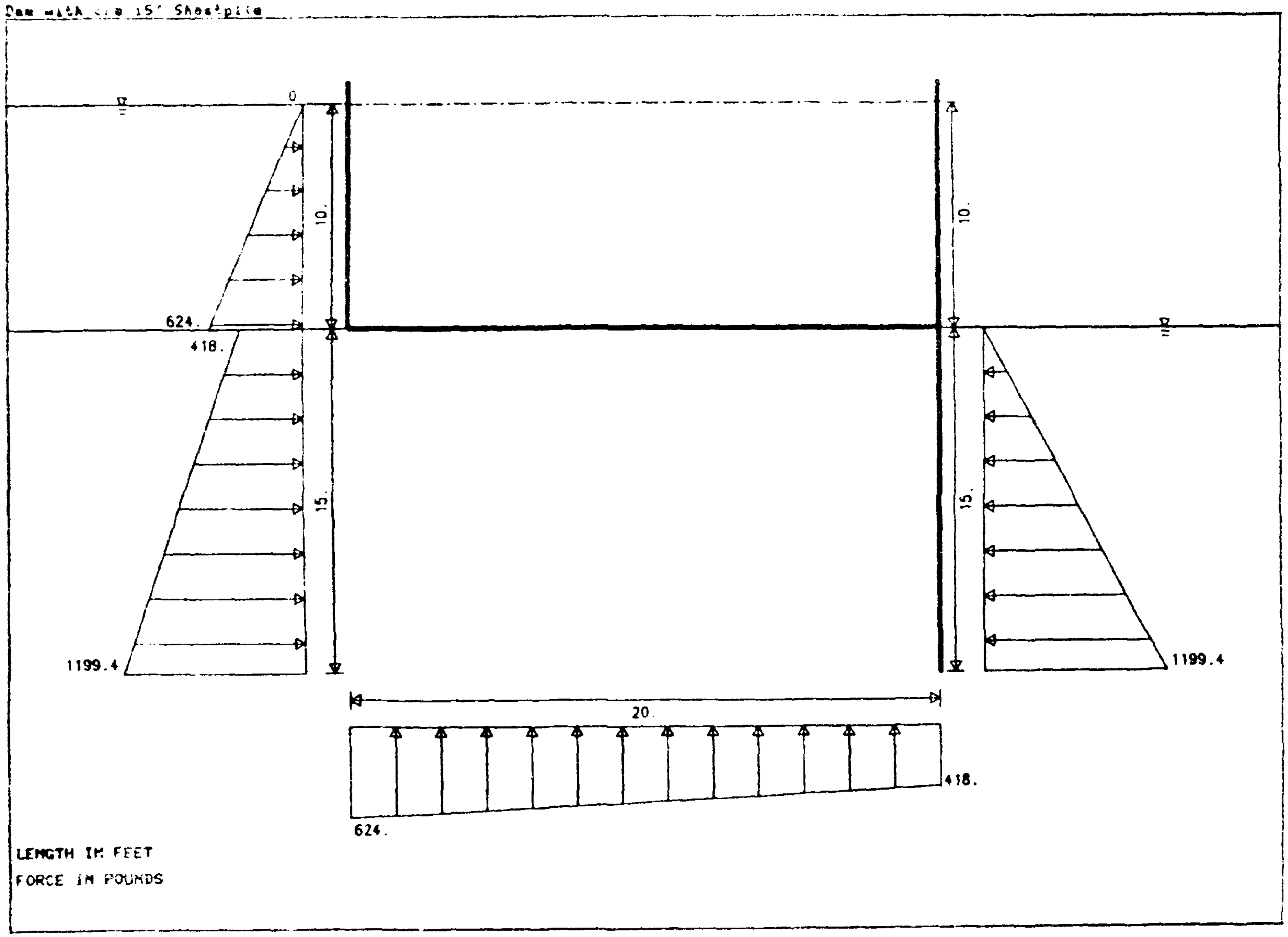

Figure C7b. Plot of pressures for Example 5

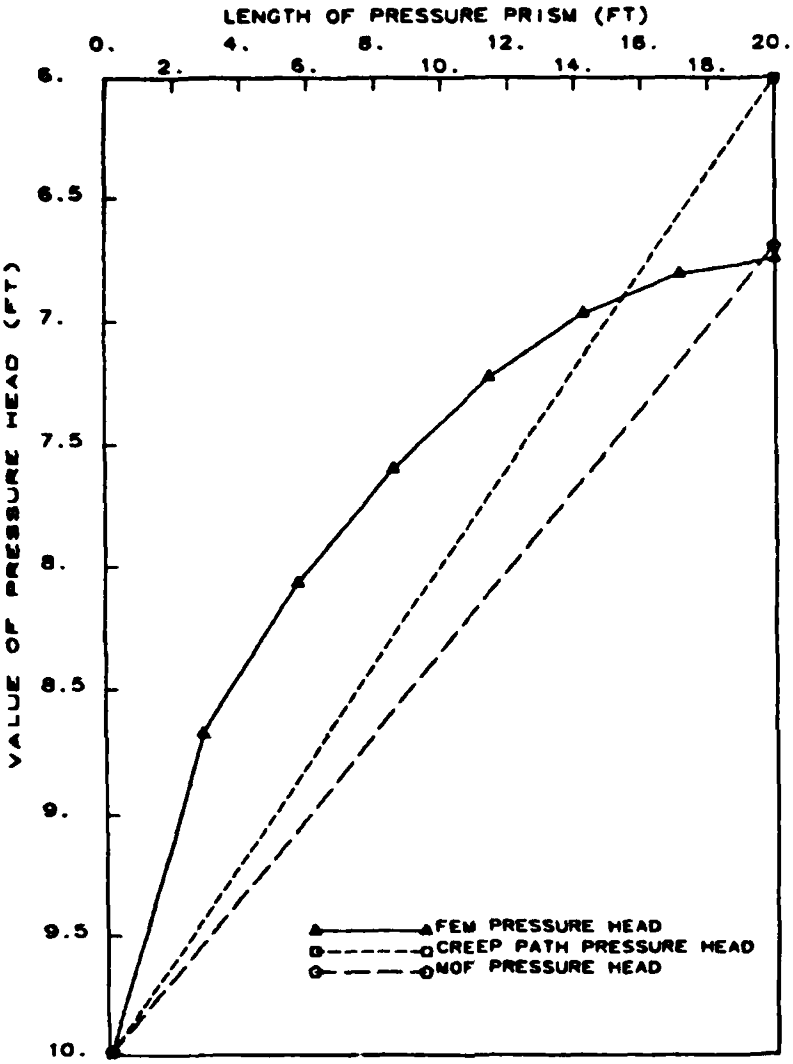

Figure C7c. Plot of uplift pressures for each method for Example 5

Table C7a

Uplift Comparison for Example 5, Dam With One 15-ft Sheetpile at Toe

Method	Total Uplift Force, lb	Location of Resultant from Left, ft	% Difference from Finite Element	
			Uplift Force	Resultant Location
MOF	10420.8	9.341	8.41	0.417
CREEP	9984.0	9.167	4.13	2.30
FEM	9580.2	9.380		

Table C7b

Total Flow and Exit Gradient Comparison For Example 5, Dam With One 15-ft Sheetpile at Toe

Method	Total Flow ft^3/day	Exit Gradient	% Difference from Finite Element	
			Flow	Exit Gradient
MOF	60.8	0.1686	7.44	3.01
FEM	65.5	0.1636		

Example 6, Dam With One 15-ft Sheetpile at Heel

8. As shown in Figure C2f, Example 6 is a dam with one 15-ft sheetpile at the heel. The method of fragments solution is shown in Figures C8a and C8b. A plot of the uplift pressures for each method is shown in Figure C8c. The uplift comparison is shown in Table C8a. The total flow and exit gradient are compared in Table C8b.

```
    CONFINED FLOW - METHOD OF FRAGMENTS
    TIME: 11:31:27                          DATE: 8/11/83

TITLE - Dam with one 15' Sheetpile
Q =   60.7944 (FT**2/DAY)
K =   14.4000 (FT/DAY)
Q/K =     4.22 (FT)
TOTAL HEAD LOSS =   10.00 (FT)
```

FRAG NO.	FRAG TYPE	L (FT)	A (FT)	B (FT)	T (FT)	S1 (FT)	S2 (FT)	FORM FACTOR	HEAD LOSS (FT)
1	2				30.00	15.00		1.00	4.22
2	3			20.00	30.00	15.00		1.37	5.78

```
WARNING - THERE IS NO EMBEDMENT ON THE TAILWATER SIDE.
EXIT GRADIENT IS INFINITE AND PIPING MAY OCCUR.
```

RESULTANT FORCES ON STRUCTURE

LATERAL FORCE HEADWATER SIDE (LBS)	UPLIFT FORCE (LBS)	LATERAL FORCE TAILWATER SIDE (LBS)
17524.2	2060.3	11269.4

```
DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO.
=Y
```

Figure C8a. Program output for Example 6

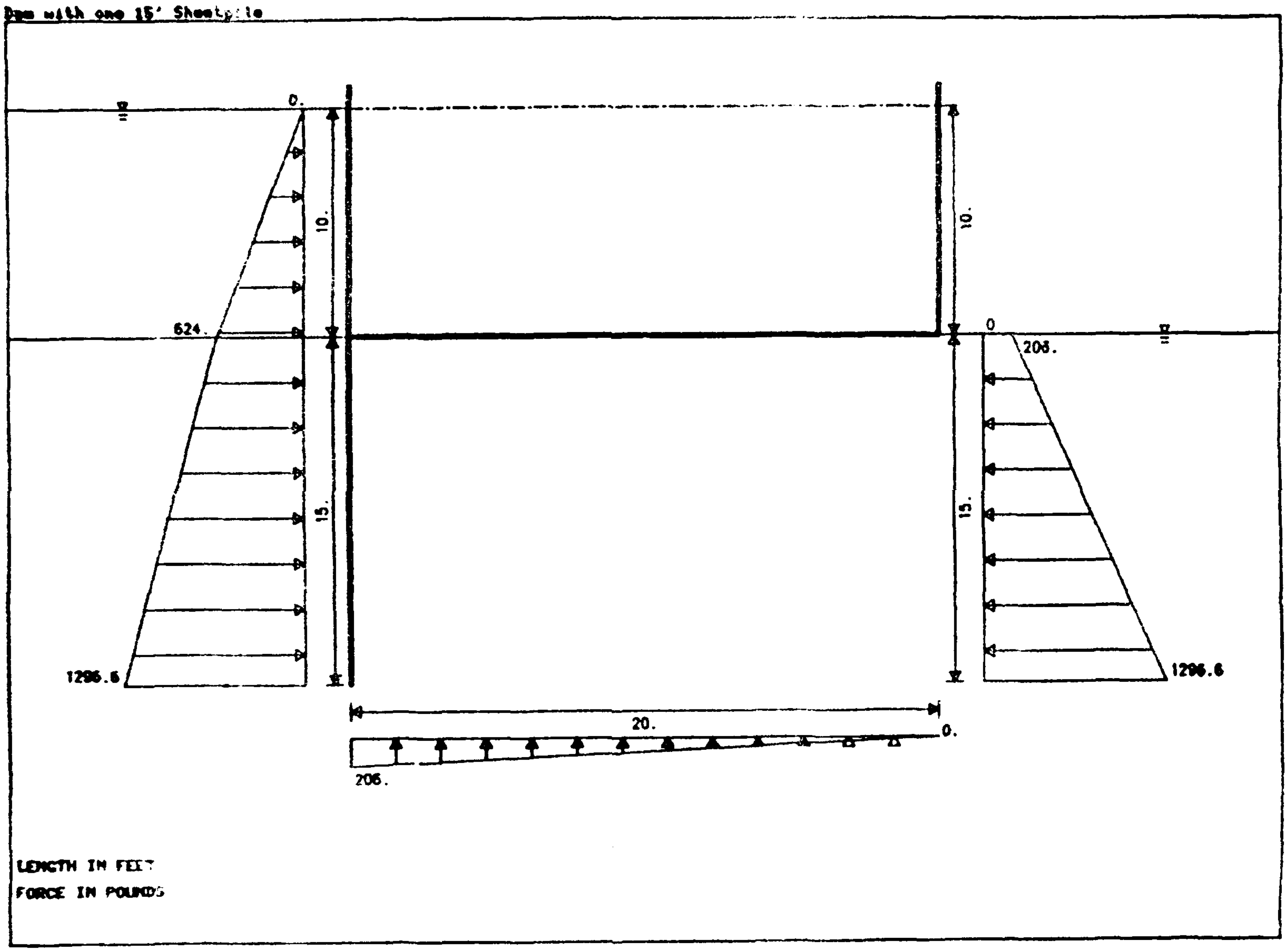

Figure C8b. Plot of pressures for Example 6

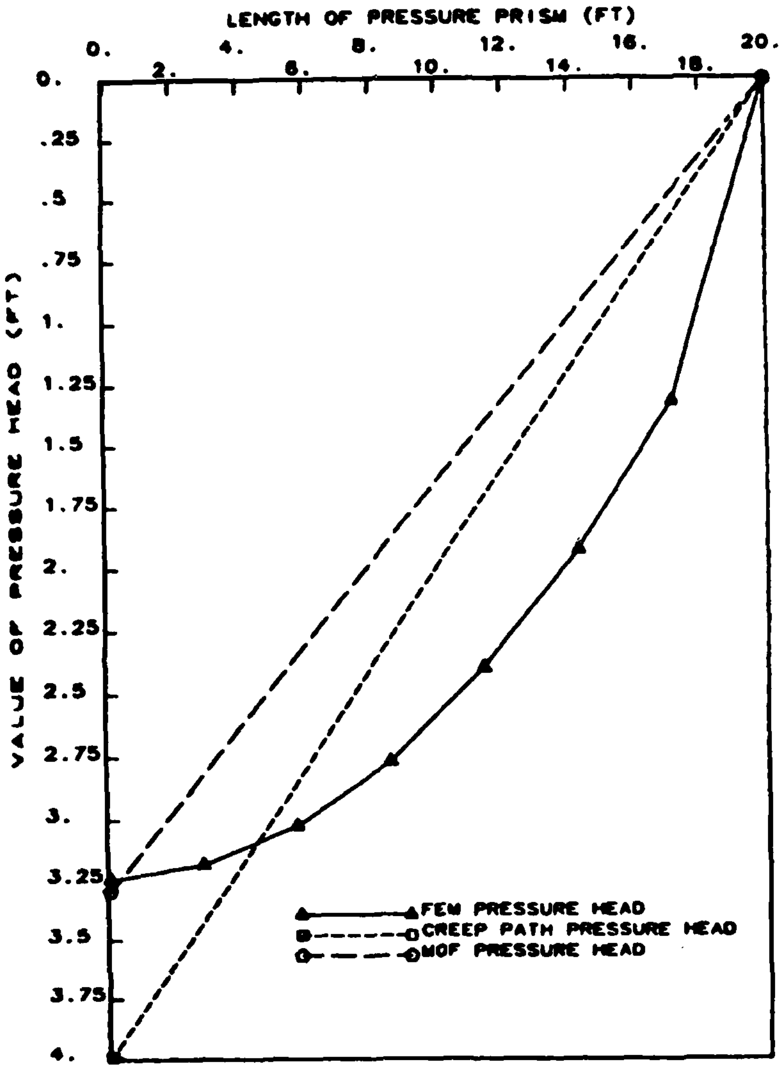

Figure C8c. Plot of uplift pressures for each method for Example 6

Table C8a

Uplift Comparison for Example 6, Dam With One 15-ft Sheetpile at Heel

Method	Total Uplift Force, lbs	Location of Resultant from Left, ft	% Difference from Finite Element	
			Uplift Force	Resultant Location
MOF	2059.2	6.667	33.90	17.57
CREEP	2496.0	6.667	14.97	17.57
FEM	2899.8	7.951		

Table C8b

Total Flow and Exit Gradient Comparison for Example 6, Dam With One 15-ft Sheetpile at Heel

Method	Total Flow ft^3/day	Exit Gradient	% Difference from Finite Element	
			Flow	Exit Gradient
MOF	60.8	*	7.44	*
FEM	65.5	*		

* Infinite exit gradient for case of no embedment on downstream side.

Example 7, Dam With Two 15-ft Sheetpiles

9. As shown in Figure C2g, Example 7 is a dam with two 15-ft sheetpiles. The method of fragments solution is shown in Figures C9a and C9b. A plot of the uplift pressures for each method is shown in Figure C9c. The uplift comparison is shown in Table C9a. The total flow and exit gradient are compared in Table C9b.

```
CONFINED FLOW - METHOD OF FRAGMENTS
TIME  17:13:36                    DATE:  8/ 8/83

TITLE - Dam with two 15' Sheetpiles
Q =    47.6561 (FT**2/DAY)
K =    14.4000 (FT/DAY)
Q/K =     3.31 (FT)
TOTAL HEAD LOSS =    10.00 (FT)
FRAG FRAG                                                   FORM    HEAD
NO.  TYPE    L       A       B       T       S1      S2    FACTOR   LOSS
            (FT)    (FT)    (FT)    (FT)    (FT)    (FT)            (FT)
---------------------------------------------------------------------------
 1    2                             30.00   15.00            1.00    3.31
 2    5    20.00                    30.00   15.00            1.02    3.38
 3    2                             30.00   15.00            1.00    3.31
EXIT GRADIENT =   0.1322


                   RESULTANT FORCES ON STRUCTURE
         LATERAL FORCE     UPLIFT FORCE      LATERAL FORCE
         HEADWATER SIDE                      TAILWATER SIDE
            (LBS)             (LBS)             (LBS)

           17951.2           6240.0            8568.8

DO YOU WANT TO PLOT WATER PRESSURES? YES OR NO.
=Y
```

Figure C9a. Program output for Example 7

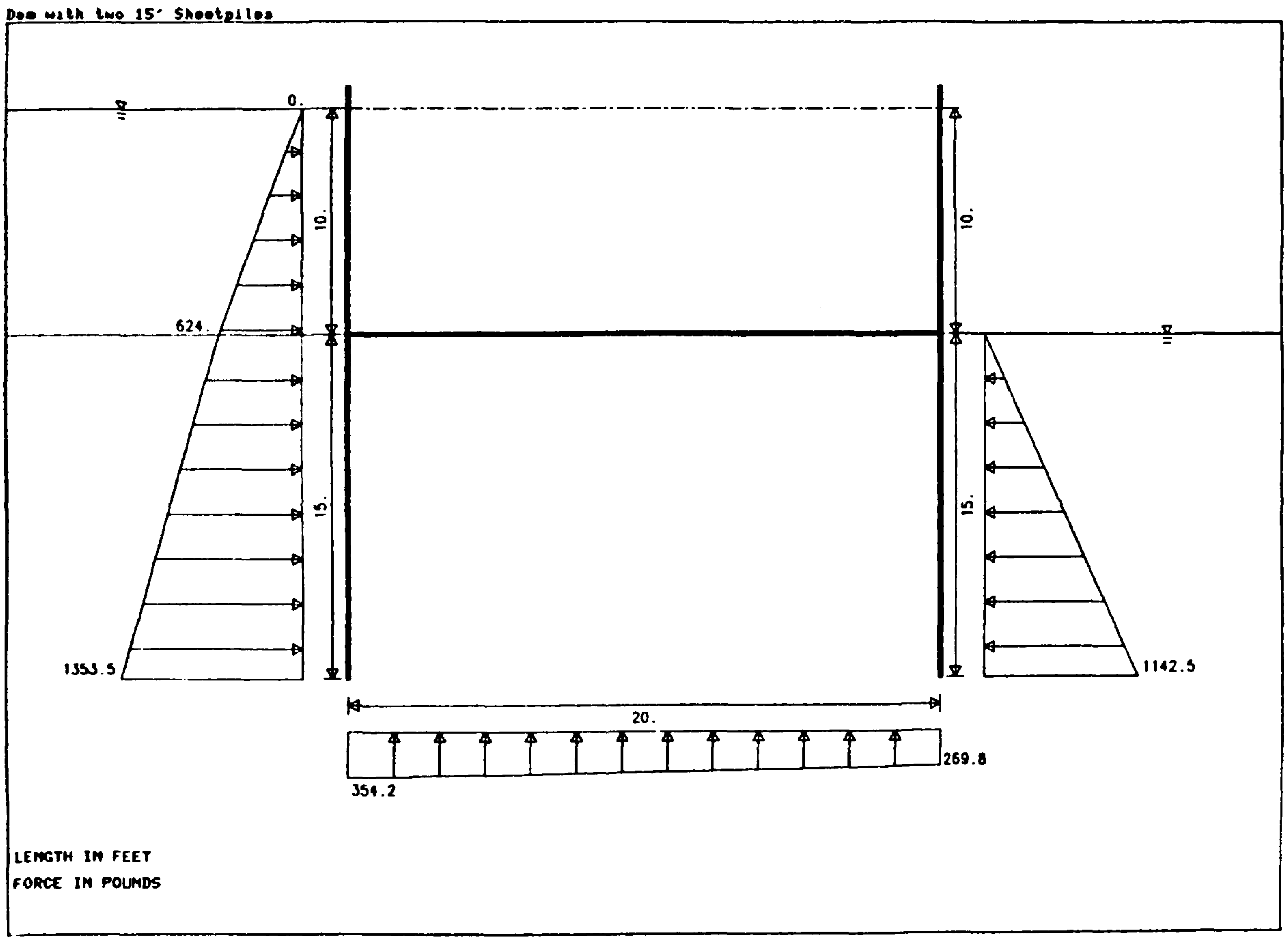

Figure C9b. Plot of pressures for Example 7

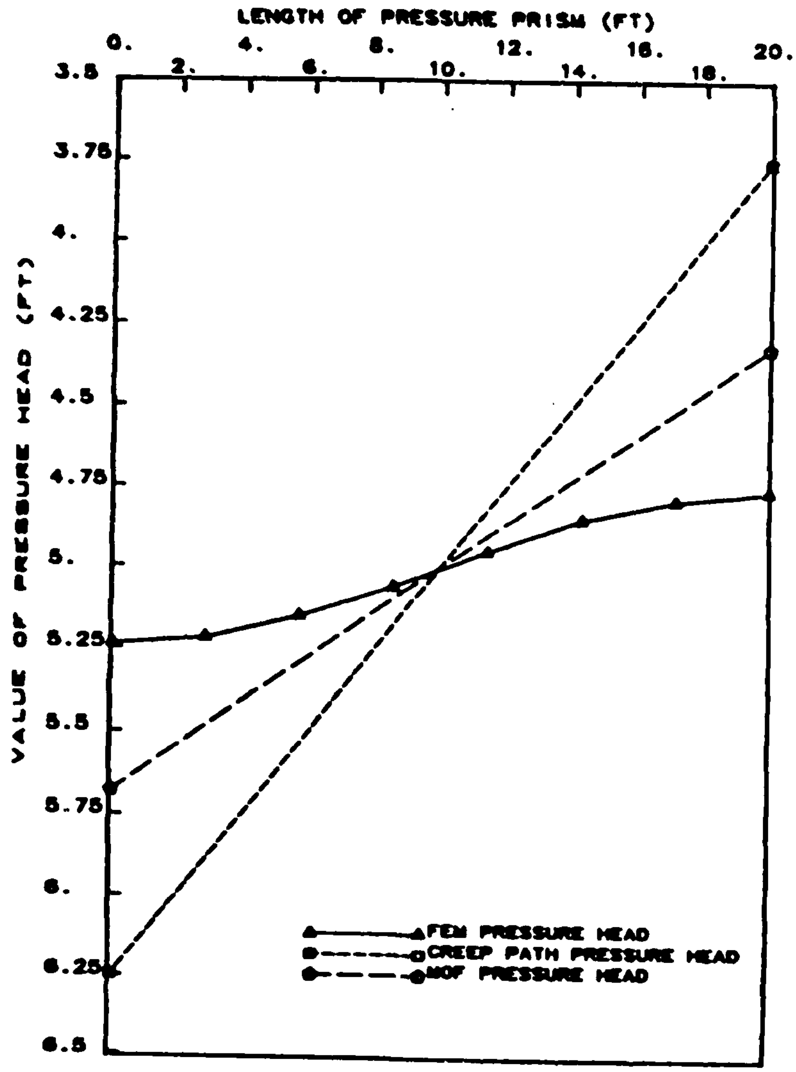

Figure C9c. Plot of uplift pressure for each method for Example 7

Table C9a

Uplift Comparison for Example 7, Dam With Two 15-ft Sheetpiles

Method	Total Uplift Force, lbs	Location of Resultant from Left, ft	% Difference from Finite Element: Uplift Force	% Difference from Finite Element: Resultant Location
MOF	6240.0	9.547	0.058	2.71
CREEP	6240.0	9.167	0.058	6.77
FEM	6243.6	9.809		

Table C9b

Total Flow and Exit Gradient Comparison for Example 7, Dam With Two 15-ft Sheetpiles

Method	Total Flow ft^3/day	Exit Gradient	% Difference from Finite Element: Flow	% Difference from Finite Element: Exit Gradient
MOF	47.7	0.1322	7.08	4.01
FEM	51.2	0.1270		

WATERWAYS EXPERIMENT STATION REPORTS PUBLISHED UNDER THE COMPUTER-AIDED STRUCTURAL ENGINEERING (CASE) PROJECT

	Title
Technical Report K-78-1	List of Computer Programs for Computer-Aided Structural Engineering
Instruction Report O-79-2	User's Guide: Computer Program with Interactive Graphics for Analysis of Plane Frame Structures (CFRAME)
Technical Report K-80-1	Survey of Bridge-Oriented Design Software
Technical Report K-80-2	Evaluation of Computer Programs for the Design/Analysis of Highway and Railway Bridges
Instruction Report K-80-1	User's Guide: Computer Program for Design/Review of Curvilinear Conduits/Culverts (CURCON)
Instruction Report K-80-3	A Three-Dimensional Finite Element Data Edit Program
Instruction Report K-80-4	A Three-Dimensional Stability Analysis/Design Program (3DSAD) Report 1: General Geometry Module Report 3: General Analysis Module (CGAM) Report 4: Special-Purpose Modules for Dams (CDAMS)
Instruction Report K-80-6	Basic User's Guide: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)
Instruction Report K-80-7	User's Reference Manual: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)
Technical Report K-80-4	Documentation of Finite Element Analyses Report 1: Longview Outlet Works Conduit Report 2: Anchored Wall Monolith, Bay Springs Lock
Technical Report K-80-5	Basic Pile Group Behavior
Instruction Report K-81-2	User's Guide: Computer Program for Design and Analysis of Sheet Pile Walls by Classical Methods (CSHTWAL) Report 1: Computational Processes Report 2: Interactive Graphics Options
Instruction Report K-81-3	Validation Report: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)
Instruction Report K-81-4	User's Guide: Computer Program for Design and Analysis of Cast-in-Place Tunnel Linings (NEWTUN)
Instruction Report K-81-6	User's Guide: Computer Program for Optimum Nonlinear Dynamic Design of Reinforced Concrete Slabs Under Blast Loading (CBARCS)
Instruction Report K-81-7	User's Guide: Computer Program for Design or Investigation of Orthogonal Culverts (CORTCUL)
Instruction Report K-81-9	User's Guide: Computer Program for Three-Dimensional Analysis of Building Systems (CTABS80)
Technical Report K-81-2	Theoretical Basis for CTABS80: A Computer Program for Three-Dimensional Analysis of Building Systems
Instruction Report K-82-6	User's Guide: Computer Program for Analysis of Beam-Column Structures with Nonlinear Supports (CBEAMC)
Instruction Report K-82-7	User's Guide: Computer Program for Bearing Capacity Analysis of Shallow Foundations (CBEAR)

(Continued)

WATERWAYS EXPERIMENT STATION REPORTS PUBLISHED UNDER THE COMPUTER-AIDED STRUCTURAL ENGINEERING (CASE) PROJECT

(Concluded)

	Title	Date
Instruction Report K-83-1	User's Guide: Computer Program With Interactive Graphics for Analysis of Plane Frame Structures (CFRAME)	Jan 1983
Instruction Report K-83-2	User's Guide: Computer Program for Generation of Engineering Geometry (SKETCH)	Jun 1983
Instruction Report K-83-5	User's Guide: Computer Program to Calculate Shear, Moment and Thrust (CSMT) from Stress Results of a Two-Dimensional Finite Element Analysis	Jul 1983
Technical Report K-83-1	Basic Pile Group Behavior	Sep 1983
Technical Report K-83-3	Reference Manual: Computer Graphics Program for Generation of Engineering Geometry (SKETCH)	Sep 1983
Technical Report K-83-4	Case Study of Six Major General-Purpose Finite Element Programs	Oct 1983
Instruction Report K-84-2	User's Guide: Computer Program for Optimum Dynamic Design of Nonlinear Metal Plates Under Blast Loading (CSDOOR)	Jan 1984
Instruction Report K-84-7	User's Guide: Computer Program for Determining Induced Stresses and Consolidation Settlements (CSETT)	Aug 1984
Instruction Report K-84-8	Seepage Analysis of Confined Flow Problems by the Method of Fragments (CFRAG)	Sep 1984

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